Management and restoration of native grassy woodland in the Midlands of Tasmania

by

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Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any tertiary institution and to the best of my knowledge and belief, the thesis contains no material previously published or written by another person, except when due reference is made in the text.

A. Zacharek.

Andrew Zacharek

Abstract

This thesis examines the effects of agricultural and conservation management practices on grassy communities in the sub-humid, low altitude Midlands of Tasmania.

The results of an extensive survey were examined to assess the effects of grazing by sheep and cattle, fertilisation and the introduction of exotic pasture species on the grassy communities.

Sites were classified according to the degree of pasture conversion and the level of the main limiting nutrient phosphorus, by annual rainfall and by geological substrate. Exotic species replaced native species with increasing degrees of pasture conversion and levels of phosphorus. Effects of management varied rainfall and different geological substrates. Raunkiaer life-form groups were a useful aid in the identification of patterns of species' responses.

Exotic therophytes and flat/versatile rosette hemicryptophytes were the most invasive exotic life-forms in native communities. The native species in the flat/versatile rosette and caespitose hemicryptophyte life-form groups were the most tolerant of disturbance. The effects of fertilisation alone on native communities were increased agricultural productivity but a reduction in the diversity of native species and the conservation values of the communities.

At the Township Lagoon Nature Reserve, three levels of grazing pressure, light in the reserve and moderate and higher levels in adjacent paddocks, were compared. The moderate level of grazing altered species composition but native species diversity declined only under the high grazing regime.

A replicated experiment, with a gas flame used to provide heat energy, compared the responses of vegetation to burning. Treatments were single burns at four different times of the year, burns at those times in two consecutive years and a no burning treatment.

Phenology varied considerably between species. Burning promoted most species when it occurred a short time before main growing season of that species. In addition, most species were suppressed by burning which occurred during their main growing season or

before seed dispersal. Burning in two consecutive years tended to increase the seasonal effects.

The effects of weeding techniques on species and life-forms in grassland dominated by exotic species were examined over a 10 month period from spring 1991. The weeding techniques were removal of topsoil, herbiciding and burning. The effects varied between species, and depended on the protection of buds from disturbance, the presence of seed for recruitment and the conditions for growth of the species.

The levels of dissimilarity between the responses of all pairs of species to disturbance in this study were calculated using the Gower metric index of dissimilarity. The degree of dissimilarity within the life-form groups was less than that between the life-form groups for only a small proportion of comparisons.

Species were classified using TWINSPAN into response or functional groups based on their responses to disturbance. Groups were classified mainly by responses to agricultural management, and the responses to grazing level, burning and weed-control techniques were highly variable. The response groups were not associated with the Raunkiaer life-form group to which the species belonged.

The responses of species classified into Raunkiaer life-form groups were highly variable. The life-form group was an aid to describing overall responses of species, but would be a poor predictor of the likely response of any one species to management.

Active management of grasslands could be used to manipulate their species composition as many species are highly sensitive to the types and levels of disturbance. Conservation management of native grassy communities must be based on the site-specific responses of individual species to disturbance.

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Contents

Contents (Continued)

Contents (Continued)

Contents (Continued)

Contents (Continued)

List of figures

List of Tables

List of Tables (continued)

List of Tables (continued)

Chapter 1. Introduction

1.1 Tasmanian lowland grassy vegetation

Australian temperate grassy vegetation is under threat from continued clearing and alteration (Groves and Williams 1981, Kirkpatrick *et al.* 1988, Kirkpatrick 1991, McDougall and Kirkpatrick 1994). Throughout Australia clearance and agriculture are major causes of plant extinction (Leigh *et al.* 1984). In 1985, after approximately 170 years of European settlement, only 17% of the original vegetation of the Midlands of Tasmania remained (Fensham and Kirkpatrick 1989). Clearing of dry country vegetation types continues at almost 1% per year (Kirkpatrick 1991).

Information about agricultural and conservation management practices on grassy communities in the sub-humid, low altitude areas of Tasmania is scarce. This thesis examines the impacts of management practices and the potential for management to improve the condition of this vegetation type.

1.2 Ecological processes in native grassy vegetation

A large amount of ecological research has taken place in grassy vegetation. A patch of grassland which contains many individual plants can be viewed by an observer, and many attributes of individual plants can be easily measured. The often rapid response of species and communities to manipulation allows results to be obtained within a short time. The accessibility and economic values of many grasslands encourages their study. There is greater probability of being able to develop and test ecological theories in grassland than in other vegetation types. Consequently, a large amount of ecological theory has been developed following work in grassy vegetation.

In grasslands and grassy woodlands worldwide, the major factors determining community composition are grazing, fire and climate (Gibson and Hulbert 1987). The changing community composition is a result of species' individual responses to complex interactions between those factors (Gibson and Hulbert 1987).

1.3 Disturbance

Disturbances are events that disrupt community structure, or change resource or substrate availability (Pickett and White 1985). In Australian grasslands, important disturbances include natural fire regimes, grazing by native animals, and extreme, natural climatic events such as flood or lightning strike. Disturbances which are associated with or caused by humans include human-mediated fire regimes, grazing by introduced stock, mechanical disturbance and alteration of soil nutrient and moisture conditions.

Disturbances create patches of bare ground, safe sites for seedling establishment (Harper 1977), and temporarily increases the availability of essential resources, nutrients, water, light and physical space (Pickett and White 1985, Tilman 1982). The intermediate disturbance hypothesis suggests that a moderate level of disturbance will result in higher species richness than either high of low levels of disturbance (Connell 1978). However, human-mediated increases of nutrient and moisture levels are important causal factors aiding the invasion of exotic species into Australian vegetation, where nutrient levels are generally low (Clements 1983, Lambert and Turner 1987, Hobbs and Atkins 1988, Hobbs 1989). The effects of fire, grazing, soil disturbance, and nutrient addition are reviewed by Hobbs and Huenneke (1992).

Whether disturbance will favour native or exotic species depends on stochastic events, the reproductive characteristics of the species and site conditions (Sousa 1984). Pre-emption of the site and/or presence of a large soil seed bank or bud reserve are likely to be major determinants of the post-disturbance outcome. The soil seed bank includes both a transient seed bank that consists of seed that mostly germinates in the season following seedfall, and longer-lived seed for which germination is delayed. The soil bud reserve is the sum of the below-ground buds.

The short-term responses of plants to disturbance also depend on the growth rates of individual species (e.g. Wilson and Shay 1990), and the ability of plant species to take advantage of temporarily high resource levels resulting from disturbance. Alterations of disturbance regimes generally result in shifts in species composition.

There are some native species that thrive under severe exogenous disturbances such as heavy grazing (Gilfedder and Kirkpatrick 1994). However, in most cases, the result is a loss of the less tolerant native species, a decrease in native plant richness and an increase in exotic plant richness (McIntyre and Lavorel 1994*a*). However, given protection from grazing on high nutrient sites, native grasses exclude some native interstitial species and cause a decrease in native species richness (Fensham and Kirkpatrick 1989).

1.4 Competition

In the extensive literature on competition, it is recognised as major factor affecting species composition and grassland community structure, dynamics and productivity (Risser 1969, Harper 1977, Grime 1979, Fowler 1986, Goldberg 1987, Tilman 1988, Aarsen and Epp 1990, Goldberg and Barton 1992).

Competition occurs between plants for the resources water, nutrients, light, O_2, CO_2, and for the agents of pollination and dispersal (Risser 1969). Competition may be the primary interaction between species (Roush and Radosevich 1985), although there is experimental evidence that positive interactions between species are important in determining community composition (Callaway 1995).

Changes in resource availability and disturbance regimes and are thought to affect species composition mainly by altering the competitive interactions between species (Vogl 1974). Competition intensity is thought to increase with increasing nutrient availability (Grime 1979). Species diverse is generally observed to decline with increasing competition (Grime 1973, Connell 1978, Huston 1979).

In studies of competition in grassland ecosystems, it has been found that the degree of competition is proportional to the mass of competing plants (Goldberg 1987). In grasslands with a relatively high root mass compared to shoot mass, competition occurs for below ground resources (Coffin and Urban 1993, Wilson 1988, 1993). This has been shown to be a critical factor in survival of grass seedlings (Aguilera and Lauenroth 1993).

There has however, been extensive debate on which resources are important and the mechanisms by which competition affects plant communities (Huston and DeAngelis 1994). Local heterogeneity in resource availability may explain co–existence of a large number of species competing for the same limiting resource (Huston and DeAngelis 1994)

Other aspects of the ecology of grasslands affect competitive interactions among species. Competitive interactions among plants in grassland are affected by accumulation and removal of litter (Knapp and Seastedt 1986)

There are few general principles for the prediction of the competitive ability of plants (Grime 1973). Attempts have been made to predict competitive ability from morphological or physiological attributes of plants (eg. Gaudet & Keddy 1988, Epp & Aarsen 1989). However most studies have been conducted in high nutrient conditions (Huston and DeAngelis 1994).

1.5 Community structure

The community structure of grassland in Britain as described by Grubb (1986) consists of a matrix of perennial grass species, within which is an interstitium of short-lived and ephemeral plants regenerating in the gaps. A similar idea developed for North American tall-grass prairies describes a core of perennial tussock grasses and a number of ephemeral satellite species (Glenn and Collins 1990). Tremont and McIntyre (1994) describe Australian temperate grassy vegetation as larger perennial tussock grasses forming a matrix for smaller statured grass species, graminoids and forbs.

Moderate to heavy grazing, mechanical disturbance and nutrient addition generally cause the destruction and replacement of the larger tussock grasses and the replacement of intersititial species by exotic annual, biennial and perennial grasses and forbs (Moore 1970, Mack 1989).

The exotic species that are the most serious invaders of grassland and grassy woodland include annual grasses, perennial caespitose and rhizomatous grasses, graminoids, annual, biennial and perennial rosette forbs, and shrubs (Carr *et al.* 1992). A number of

these species are cultivated as pasture and crop species and others are 'weedy' species associated with and promoted by agricultural practices. Another important suite of exotic species is garden escapes.

1.6 Life-form groups and functional attributes of species

The use of ecological characters to classify species and to understand their responses to disturbance is a consistent theme in ecological literature. There have been a number of widely varying classificatory approaches used. Classificatory approaches may be based on morphology, phenology, life-history, growth and regeneration strategies and taxonomic affiliation.

The responses of species to disturbance regimes can be understood by their vital attributes (Noble and Slatyer 1980) and life histories (Sousa 1980). A model which classifies species according to strategies based on competitive ability, tolerance of stress and ability to take advantage of disturbance, is the C-S-R model of strategies (Grime 1979).

Analysis of responses of species to disturbances, based not on particular characteristics but groups of functional characteristics, is considered to be a useful tool in understanding community interactions and the responses of species to long-term disturbance regimes (Newsome and Noble 1986). Leishman and Westoby (1992) beginning with most or all the possible traits that could be important, identified clusters of traits using multivariate techniques. These clusters corresponded mainly to growth form, and vegetative, life-history and phenological traits were correlated within groups of species. Friedel *et al.* (1988) used similar clustering methods in rangelands and found that clusters corresponded largely to growth form but also to palatability.

Classification of species into life-form groups is based on the position relative to the ground surface of the highest perenating buds from which new growth can originate. Differences in growth forms and positions of buds were noted for grassland plants, and these characteristics were associated with apparent responses to either grazing or protection (Noy-Meir *et al.* 1989).

The Raunkiaer system was designed for broad classification of plant distribution on regional and continental scales based on climate. It was not designed necessarily for the evaluation of local species responses to disturbance. However, Tremont and McIntyre (1994) and McIntyre *et al.* (1995), in studies in the grasslands and grassy woodlands of the northern N. S. W. Tablelands, found that life-form based on a modified version of Raunkaier life-forms (Raunkiaer 1934), was a useful characteristic for describing the response of vegetation to disturbance.

Other characteristics, such as the seed dispersal mechanism, mobility of the seed and the occurrence of vegetative reproduction of the species, were associated with responses to some types of disturbance, particularly soil disturbance.

Tremont and McIntyre (1994) stress the need for a consistent approach to assist in co-ordination and synthesis of the diffuse base of information of species responses to disturbance that currently exists. Tremont and McIntyre (1994) and McIntyre *et al.* (1995), in studies in the grasslands and grassy woodlands of the northern N. S. W. Tablelands, found that life-form based on a modified version of Raunkaier life-forms (Raunkiaer 1934), was a useful characteristic for describing the response of vegetation to disturbance. Other characteristics, such as the seed dispersal mechanism, mobility of the seed and the occurrence of vegetative reproduction of the species, were associated with responses to some types of disturbance, particularly soil disturbance.

For the development of a consistent approach to the description of vegetative response, life-form (*sensu* Raunkiaer) appears to be a useful characteristic. It could be used as the basis of a classificatory scheme to describe vegetation responses to disturbance and to predict likely outcomes of management regimes. The incorporation of other characteristics such as palatability, stature, origin and phenology could introduce more detail and greater specificity to the classification and may be appropriate depending on the context. However, a potential failing of classification using characteristics such as life-form is that it involves preconceptions of what is likely to be important (Leishman & Westoby 1992).

1.7 The vegetation of the dry lowland areas of Tasmania

The dry lowland areas of Tasmania which are the subject of this thesis include the Midlands, Fingal Valley, upper Derwent Valley and Bothwell areas and the fringes of these areas up to an altitude of approximately 600 m (Fig. 1.1). The annual rainfall of these areas ranges from 492 mm at Tunbridge, to up to 1000 m on the fringes, however, the average rainfall for most of the area is below 700 mm/yr (Fensham 1989).

A reconstruction of the pre-European vegetation of the northern Midlands of Tasmania (Fensham 1989), showed that most of the vegetation was open grassland, grassy woodland and open forest. The occurrences of the major vegetation types were related to topography and soil type which in turn was related to geological substrate (Fensham 1989).

The major communities in order of abundance at the time of white settlement were:
Eucalyptus pauciflora/E. ovata woodland;
E. viminalis woodland;
E. amygdalina forest;
E. ovata open woodland;
Tussock grassland (*Poa labillardierei*) (Fensham 1989) — *Poa labillardierei* tussock grassland has now almost disappeared.

The close relationship between vegetation and geological substrate has been recorded with abrupt changes often seen across geological boundaries (Hogg and Kirkpatrick 1974, Kirkpatrick 1981). Gilfedder and Kirkpatrick (1993, 1995), surveyed 100 bush remnants of 5 to 100 ha in area and reported that the condition of remnants was most strongly related to management, with the remnants containing the highest species richness being subject to either very low grazing pressure or periods of no grazing.

Today, almost all the sub-humid, low altitude areas including the Midlands, Fingal Valley, upper Derwent Valley and Bothwell areas are privately owned and managed for agricultural production. Agricultural management practices, including cropping, grazing by sheep and cattle, fertilisation and introduction of exotic pasture species, are employed in differing patterns over a varied landscape. Relatively unaltered native grassy vegetation exists on large areas of 'run country' which is managed for grazing.

There are only two official nature reserves in the area, the Tom Gibson Nature Reserve (660 ha) at Epping Forest and the Township Lagoon Nature Reserve (TLNR) of 16 ha located at Tunbridge. TLNR contains areas of high quality native grassy vegetation, dominated by *Themeda triandra* (kangaroo grass) with a number of native species that are rare and threatened or that are reserved only in this one place (Kirkpatrick *et al.* 1988, Kirkpatrick *et al.* 1991***b***). The nature reserve also contains exotic grass swards that have been created by mechanical disturbance and nutrient enrichment, following rubbish dumping operations. These areas are found near, and interspersed amongst, the areas of intact *Themeda triandra* dominated grassland.

TLNR and the adjoining areas were selected to examine the effects of different levels of grazing, burning in different seasons in one year and with a second burn in the following year, and weeding techniques. The aim was to investigate management techniques which allow the manipulation of species composition with an aim of reducing exotic species and favouring the increase of native species.

Relatively unaltered native grassy vegetation is often found as small, isolated remnants, some of which contain a high number of rare and threatened native higher plant species (Kirkpatrick *et al.* 1988, Kirkpatrick and Gilfedder 1995). This pattern of remnant native vegetation in the non-native agricultural landscape is analogous to isolated islands as described by island biogeography (MacArthur and Wilson 1967). Interestingly, relatively altered 'weedy' remnants contain some of the rarest native plant species (Kirkpatrick and Gilfedder 1995).

In the open plains of the northern Midlands and adjacent valleys, the native vegetation has almost all been cleared and converted to exotic pasture, crops, towns and infrastructure. The deeper arable soils were the most attractive to the early settlers. On the steeper slopes of dolerite hills above the plains extensive areas of rough country have been grazed. The pastures are generally native and unaltered apart from grazing by stock, and are on shallower, rockier, non-arable soils. The varying degrees of alteration of the vegetation on fringes of the Midlands create complex patterns of species distribution (Gilfedder and Blake 1995). These patterns resemble the variegated landscape model of McIntyre and Barrett (1992). Other areas settled early, and largely

cleared, include the less extensive valleys and plains of the Upper Derwent Valley, the Bothwell area and areas on the east coast of Tasmania.

The most important land uses of remaining native grassy woodland in the Midlands and other dry lowland areas are grazing by sheep and cattle and cropping, therefore native grassy woodlands and semi-native vegetation are important economically. Thirty-eight percent of the 1.3 million ha of all pastures in Tasmania remain native or semi-native (Thompson 1995). Sheep tend to be grazed on drier pastures and at higher altitudes. Approximately 50% of the area of pastures in Tasmania grazed by sheep are native or semi-native. This includes both lowland areas and higher altitude pastures such as on the Central Plateau. Approximately 50% of all wool grown is from native and semi-native pastures. In other states, native and semi-native pastures also have important economic value, for example, they cover 70% of the 2.9 m ha Northern Tablelands of NSW (Lodge and Whalley 1985).

1.8 Agricultural management

1.8.1 Cropping and pasture improvement

Cropping and pasture improvement cause the near-complete replacement of native species. Where exotic pasture establishment is only partially successful, propagules of native plant species may persist and later become dominant in the pastures.

Exotic pasture species commonly used in the dry lowland areas of Tasmania are the grasses *Lolium perenne* (perennial ryegrass), *Dactylis glomerata* (cocksfoot), *Festuca arundinacea* (fescue), *Phalaris aquatica* (phalaris), and the legumes, *Trifolium subterraneum* (subterranean clover) and *Trifolium repens* (white clover) (Thompson 1995).

These species are sown by conventional cultivation, direct drilling and surface or aerial sowing of seed. Conventional cultivation involves ploughing usually more than once, and may include deep disturbance of soils. A herbicide is usually applied in conjunction with the cultivation, and in some cases a crop is grown on the site and harvested the

season before the pasture species are sown. Direct drilling usually involves the use of a herbicide before the sowing of seed with a seed drill.

Fertilisers containing phosphorus have been applied to pastures since at least the 1930s. The natural levels of the nutrients nitrogen, phosphorus and potassium in Tasmanian soils limit pasture production. Nitrogen requirements for productive pasture species are usually met by N-fixation by introduced legumes (Nicholls and Dimmock 1965).

Currently fertiliser usage is between 5 and 10 kg of phosphorus per ha at sowing time and occasional addition at variable rates afterward (Thompson 1995). Potassium and nitrogen are also added. A cover crop of an annual grass such as oats (*Avena sativa*) is often sown with the pasture species to provide early cover for seedlings. Individual eucalypt trees may be left standing (Halpern 1974).

Aerial sowing refers to surface sowing of seed of *Trifolium subterraneum* and sometimes introduced grass seed, mainly *Lolium perenne*, together with fertiliser, either from a ground vehicle or from the air. This practice is common in non-arable areas and, if successful, results in the addition of a clover component to the vegetation. Carrying capacity of a pasture may be increased up to a factor of 4.

Sowing practices and management practices that follow on vary considerably. Correct practice under favourable conditions can result in the complete replacement of the original standing vegetation, although seed and vegetative propagules may remain. Continued management is required to maintain the dominance of sown species. In less favourable conditions, such as in a dry year or in less than ideal soil and climatic conditions, the pasture establishment may be only partially successful. In some pastures, usually in drier areas, the sown species decline over time and the pastures may become dominated largely by exotic annual grasses or native perennial grasses. These pastures are described as having 'run out'.

1.8.2 Grazing management

The most common form of grazing management in native and semi-native pastures is 'set stocking', which refers to the keeping of stock on the pastures year round. Grazing

management which involves the removal of stock for a period is also referred to as set stocking, and is common on native and semi-native pastures in Tasmania. This removal of stock is termed 'resting' or 'spelling'. Spelling often occurs in spring when sufficient or excess feed is available in the improved pastures, which have their highest productivity then. Some landowners may also have access to higher altitude pastures to which they move their sheep and cattle to graze in the spring.

Common stocking rates on the native Tasmanian 'run country', are 0.5 to 1 dry sheep equivalent DSE ha^{-1}. The term dry sheep equivalent refers to a non-lactating sheep.

Set stocking rather than rotational grazing has been recommended as the most productive way of managing stock (Willoughby 1970, Halpern 1974, Partridge 1992). In Tasmania it is the most common form of grazing management on the run country. However, a form of rotational grazing, in which stock spend only a short time in a paddock before being moved on to the next, is being adopted by some landholders. The effects of this management regime on native pastures is not yet known.

As well as sheep and cattle, native marsupial grazers and browsers, including wallabies and possums, and introduced species such as deer and goats, may be present. The presence of large numbers of unmanaged grazers may result in considerably higher effective stocking rates than could be calculated on the basis of managed stock alone.

1.8.3 Effects of grazing

Plants and plant communities are affected by grazing primarily through defoliation, however the responses of native grassy vegetation to the effects of defoliation, variation in climate, addition of nutrients, fire and trampling are complex (Scanlan *et al.* 1991, Wilson 1990). The effects of grazing on plants vary with the intensity of grazing and the rest periods given to the vegetation. However, the stocking rate, averaged over the year, is regarded as most important measure of the grazing pressure. The type of grazing system, whether continuous or rotational, is not recognised as important (Partridge 1992).

The grazing pressure over a paddock varies with the behaviour of the grazers, which is related to topography and surface features such as proximity to cover, slope and aspect (Wilson 1990). Typically in Tasmania, dry north-facing slopes are often overgrazed, and wetter, south-facing slopes are undergrazed within the same paddock.

It is possible to manipulate pasture composition by altering the timing of grazing and rest periods to coincide with crucial stages in the life histories of particular species (Lodge and Whalley 1985). Generally, not much is known about maintenance of pasture composition (Archer 1989, Kemp *et al.* 1995), and it follows that not much is known about how to influence it.

The intensity of grazing on vegetation is highly variable. The grazing behaviour of stock can be selective of particular plant species, individuals within species, and can vary over space and time (Huntly 1991).

The effects of grazing depend on the selectivity of the herbivore, and the tolerance of the plants to defoliation (Wilson 1990). Defoliation influences the growth, recruitment and mortality of plants and lowers the height of the vegetation, reduces amounts of litter and increases bare ground (Huntly 1991). Sheep and cattle, although regarded as generalist herbivores, are selective, preferring annual plants where available, and the soft, green tissues of perennial species (Wilson 1990). Sheep tend to be more selective than cattle and graze closer to the ground (Wells 1969).

Wild herbivores include: Bennett's Wallabies, Forester Kangaroos (Eastern Grey Kangaroos), Common Brushtail Possums, and introduced rabbits, goats and deer. Native herbivores have different grazing behaviour to sheep and cattle. For example, Eastern Grey Kangaroos on mainland Australia are selective grazers and feed mainly on grasses, and may or may not feed on clovers (*Trifolium* spp.) (Robertson 1985). Besides grazing some species also browse.

The effects of grazing on individual plants depend on the palatability of the plant (which affects the selectivity of the herbivore for that plant) and on the plant's tolerance of the various effects associated with grazing. Tolerance of defoliation by plants depends on the morphology of the plants, the position of perenating buds, and their tolerance to loss of tissue and the rate of tissue replacement. The result of moderate to heavy grazing by

herbivores is a decrease in palatable perennial forbs and grasses, and an increase in annuals and unpalatable perennial forbs and grasses (Wilson 1990). Perennials that are green and palatable at times when feed is available will be heavily grazed. Thus perennial species are subject to longer periods of grazing pressure and have declined (Mack 1989, Moore 1970). Generally, plants that grow upright and are of taller stature are more affected by grazing.

Grazing in south-eastern Australia has generally resulted in the replacement of tall native perennial grasses with shorter native grasses, which are more tolerant to grazing. In areas of higher grazing intensity these tend to be replaced by introduced annual grasses and herbs (Moore 1970, Robinson and Dowling 1976). The position of the species in a sequence of replacement of native species depends on the tolerance of the species to the grazing regime (Moore 1970).

Kangaroo grass (*Themeda triandra*) was once common throughout most of south-eastern Australia. Kangaroo grass is only palatable to stock when young (Leigh and Holgate 1979, Whalley *et al.* 1978), yet is intolerant of frequent grazing (Hodgkinson *et al.* 1989). It has disappeared with heavy grazing both in Africa and Australia (Foran *et al.* 1978, Tremont and McIntyre 1994, Mott and Tothill 1984). In Tasmania, grazing alone has been associated with decreases of kangaroo grass and increases in shorter grasses (Fensham and Kirkpatrick 1989).

In contrast, the tall tussock-forming *Poa sieberiana* has probably not declined with grazing in Northern NSW (Tremont and McIntyre 1994). *Poa labillardierei* of Tasmania and Victoria is very similar to *P. sieberana* — older *P. labillardierei* leaves become tough, fibrous and unpalatable and *P. labillardierei* may become dominant with sheep grazing and fertilisation (Groves 1974, Groves *et al.* 1973). The difference in grazing response between these two relatively tall species, seems to lie in tolerance to defoliation and the ability to utilise nutrients.

Wallaby grasses (*Danthonia* spp.) form low tussocks, are cool season perennial grasses and are tolerant of grazing. They are less common in undisturbed native vegetation than pastures and may have increased since human settlement. The Tablelands and the Goulburn districts of NSW have both improved and native paddocks with *Danthonia*

(Robinson *et al.* 1993, Lodge and Whalley 1985). *Danthonia* spp. produce green forage in winter and spring, and can have high grazing value (Lodge and Whalley 1983).

Grazing animals deposit faeces and urine and modify the seed dispersal of plants. Soil disturbance and fertilisation each increase the effects of grazing (Robinson and Dowling 1976). Soil disturbance and fertilisation have interactive effects which further favour exotic species (Hobbs and Atkins 1988).

1.8.4 Effects of grazing on communities

Degradation under stock grazing pressure, common to temperate grasslands and grassy woodlands worldwide, involves the destruction of dominant caespitose grasses and the selective removal of smaller native forbs, grasses and graminoids that are less tolerant of trampling by large, hard-hoofed animals, heavy grazing and other agricultural practices (e.g. Mack 1989).

Reduction of biomass in grassy communities is important, as it may reduce the dominance of a few native tussock grasses, and so promote new growth and create opportunities for germination and establishment of smaller intertussock species (Groves 1974, Kirkpatrick 1986).

A lack of disturbance in native grassy communities on fertile ground results in the dominance of larger tussock species and a decrease in recorded species richness (Fensham and Kirkpatrick 1989). A moderate level of grazing generally results in higher species richness compared to no disturbance (Fensham and Kirkpatrick 1989, Stuwe and Parsons 1977). The effect varies between different substrates with an increase in native species richness on sites with clay to loam soils, yet no increase on sandy soils (Fensham and Kirkpatrick 1989).

1.9 Burning

1.9.1 Importance of burning in native grasslands and grassy woodlands

Burning is seen as an important factor in maintaining ecological stability, therefore, the ecological effects of burning need to be assessed (Trollope 1984). There is a lack of information on the effects of burning on temperate grassy communities in many parts of the world including southeastern Australia (Lunt 1991), South Africa (Trolloppe 1984), and the USA (Glenn-Lewin *et al.* 1990). The lack of data is possibly due to perceptions of fire as a deleterious phenomenon in the past and, more recently, to methodological difficulties.

Fire should be regarded as a disturbance in grassland (Collins 1990). A natural (endogenous) fire regime may not have existed in Tasmania before Aboriginal settlement. It is agreed by historians that Aborigines in Tasmania and southeastern Australia used fire for the management of native grassland and grassy woodland. Large areas were regularly burned, in what was a skilled use of fire for hunting and vegetation management (TFRC 1994). Following the elimination of Aborigines from most of Tasmania in the 1830s, the anthropogenic Aboriginal fire regime was replaced by that of the Europeans, and the exogenous patterns of fire management were altered.

Until the 1970s fire was commonly used on run country to stimulate the production of new green shoots of mainly native tussock grasses for grazing by sheep and cattle. Burning was commonly conducted in spring or early summer. There was also an added benefit of fuel reduction. The practice declined with increasing labour costs for lighting fires and decreasing returns in the wool industry (TFRC 1994).

Since the devastating wildfires in 1967 in Tasmania, use of fire has been seen as more risky and, coupled with the increased regulation of burning practices, may have contributed to the decrease in rural use of fire. In South Africa a similar reduction in burning with stricter guidelines has occurred in recent decades (Trollope 1984).

Currently fire is not commonly used in pastoral management in lowland agricultural areas and the use of fire for fuel reduction is regulated. There is still, however, common

use of burning in higher altitude grassland to stimulate new shoots for grazing (Cubit 1995).

1.9.2 Burning and grazing management

Fire is a tool used in the management of tropical pastures in northern Australia and, until the 1960s, was also used in Tasmania (TFRC 1994). Fire is used in pastoral management to: reduce herbage mass and litter, stimulate growth, and manipulate species composition including removal of undesirable species. For example, burning of native pastures in Queensland is recommended at not more than a three-year interval to remove litter, stimulate growth, alter pasture composition and prepare seed beds (Partridge 1992).

At most time of the year temperate pastures are grazed to low levels. Excess production of grass can be harvested and stored as hay or silage, and there is no need for extra biomass reduction. In temperate pastures of southeastern Australia, grazing effectively controls woody species by preventing tree and shrub establishment. In most grassy areas the build up of fuel is low compared to forests and consequently the fire risk is lower (Fensham 1992).

Fire can be used for weed-control, including woody weeds. However, many weeds are able to flourish under adverse conditions and survive disturbances including fire (Christensen and Burrows 1986). Selective herbicides are used instead, although fire is valuable for weed-control if used in conjunction with other management techniques (Johnson and Purdie 1981).

1.9.3 Burning and conservation management

Burning is seen as an important ecological process in Tasmanian parks and reserves. In southeastern Australia grasslands and native grassy woodlands stock grazing generally results in a lower richness of native species and fewer rare species (Stuwe and Parsons 1977, Scarlett and Parsons 1992, Lunt 1990, 1991). Burning is therefore seen as the

most appropriate management as it is seen as having less selective effects than grazing (Robertson 1985).

Regular burning is associated with high native species richness (Stuwe and Parsons 1977). Without defoliation of *Themeda triandra*, the size of *T. triandra* tussocks and amount of litter produced results in reduced native species richness.

Groves (1974) and Stuwe (1986), recommend a burning interval of three years to be an adequate frequency of defoliation for *Themeda triandra* tussocks, while burning for conservation management is recommended at three- to five-year intervals by Robertson (1985), Kirkpatrick (1986) and McDougall (1989*a*).

In *Themeda triandra* dominated native grassland and native grassy woodland in southeastern Australia there are little data on results of different seasons and frequencies of burning (Lunt 1991). A more sophisticated use of management techniques requires detailed knowledge of responses of species to fire (Lunt 1991). Burning may have the potential to be an important tool in the maintenance of ecological stability in native pastures and the manipulation of species composition. However, without basic research and the development of background experience of fire use, its potential value will not be realised.

1.10 Restoration of native grassy communities

Restoration projects include the introduction of native species into pre-existing native vegetation, partial restoration of the complement of species previously existing at a site, or the restoration of the full complement (Jordan *et al.* 1989). The successful restoration of native plant communities would require an understanding of community structure and processes, and the characteristics and functioning of species.

The first attempts at restorations of natural communities were prairie reconstructions in mid-west USA in the 1930s and 1950s (Cottam 1987). These attempts have provided insights into the dynamics and functioning of both the restored species assemblages and natural intact communities, insights that would not have been available through observations of the intact communities alone (Harper 1987).

The aesthetics, hardiness and low maintenance properties of native Australian grassy vegetation are being recognised (Lodder *et al.* 1989, Hitchmough *et al.* 1989). This has led to research into the establishment of native grasses following sowing of seed. Research includes investigation of the seed biology, sowing methods and germination and establishment of the seed of *Themeda triandra* (Hagon *et al.* 1975, McDougall 1989*a*, Stafford 1991, Sindel *et al.* 1993), *Danthonia* spp. (Hagon *et al.* 1975, Chivers 1991) and research into the seed biology of a range of native forbs (Willis *et al.* 1988/89).

The transplanting of established plants in pre-existing swards has been successful in the UK and the USA (Wells 1989, Pavlik *et al.* 1993). Scarlett and Parsons (1992) created a new population of a rare forb by planting mature plants into pre-existing vegetation. Guidelines were developed for the broadscale revegetation of degraded Australian rangelands involving exotic grasses (Roundy and Call 1988, Silcock 1988). However, there are no documented cases of restoration of native grassy vegetation in Australia.

1.10.1 Weed-control techniques

Competition for resources with existing vegetation, and climatic and edaphic conditions, are likely to be the major determinants of the success of establishment following germination and the survival of plantings. Site-preparation techniques to reduce or eliminate weed species, and therefore reduce competition pressures on newly establishing seedlings, include herbiciding, burning and mechanical treatment such as cultivation and removal of topsoil.

The aim of weeding should be to keep down exotic propagule numbers, whilst promoting native species (Groves 1989). No known studies have analysed the responses of exotic and native species to weeding treatments in natural or semi-natural grassy vegetation.

The choice of best weeding technique depends on the vegetation and the site. Integrated methods of control are likely to be the most effective (Groves 1989). The application of weeding techniques involves an understanding of ecological processes, the

characteristics of species, morphology, life-history, regeneration biology and tolerance of the treatments. There is a wide variety of herbicides available with widely varying modes of action, constituents and therefore efficacy against groups of plants.

Removing the top 3 to 5 cm of soil (scalping), removes the bulk of the soil seed bank, roots and rhizomes, and has been suggested as a method to reduce high nutrient loads (Marrs 1985) that are important in favouring exotic species invasion and persistence (Clements 1983, Lambert and Turner 1987, Hobbs and Atkins 1988, Cale and Hobbs 1991).

1.10.2 Planting and seeding methods

A comparison of the relative costs of rehabilitation techniques is provided in Dawson (1991). Techniques that could be reliably and cost-effectively be applied on both large and small scales are desirable. Direct seeding is potentially the most cost-effective technique, however large quantities of seed of native grassland species are unavailable commercially (Zacharek 1993).

Transplanting is more reliable than direct seeding, but is expensive in both labour and materials and is suitable only for small areas. However, vegetative propagation does not rely on seasonal availability of seed or selection of plants, and there is less chance of introducing undesirable species than in a seed mix.

1.11 Thesis aims

The aims of the thesis are:

1. To determine the impact of management practices on the distribution and abundance of native and exotic species and life-form groups in grassy lowland vegetation in Tasmania.

2. To determine functional groups and to determine the predictability of responses to disturbance from life-form groups and functional groups.

3. To determine appropriate management and restoration practices for grassy lowland vegetation areas managed for either or both agriculture and conservation.

1.12 Structure of the thesis

This thesis considers the agricultural and conservation management of native grassland and grassy woodland in Tasmania dry lowland areas.

The impacts on native and exotic species of agricultural management will be examined in a broad scale survey of native and semi-native pastures in lowland Tasmania (Chapter 2). The main aspects of management, grazing, nutrient addition and cultivation will be examined. These management regimes affect the largest proportion of lowland grassy vegetation in Tasmania.

Conservation management of vegetation in TLNR will be examined. The vegetation and plant communities will be described in Chapter 3. Three different levels of grazing occur in and across the fencelines which form boundaries of TLNR, and the effects of grazing level on the native and exotic species will be examined in Chapter 4.

Burning is an important management tool for grassy vegetation and the effects on the vegetation of different season of burning and the numbers of burns will be examined in Chapter 5. The effects of the weed-control techniques, topsoil removal, herbiciding and burning on exotic and native species, and the effects of the reduction in competition in

promoting the establishment of planted seedlings of native species, will be examined in Chapter 6.

Native and exotic species will be classified according their responses to the different aspects of management, to determine whether there are consistent responses within life-form groups (Chapter 7). In Chapter 8 the conclusions which could be drawn regarding the thesis aims will be discussed and the impacts of the different aspects of the management of native grassy vegetation on native and exotic species, life-form groups and major taxonomic groups of plants will also be discussed.

Chapter 2. Responses of native and exotic species to aspects of pasture improvement and grazing management in native, semi-native and improved pastures

2.1 Introduction

The Department of Primary Industry and Fisheries (Tasmania) conducted an extensive survey of improved, semi-native and native pastures between September 1992 and January 1993. The aim of the survey was to document the types and condition of pastures grazed mainly by sheep in the dry lowland areas of Tasmania (Fig 2.1).

The survey covered 354 sites on 98 properties. The large number of sites and comprehensive collection of data provides an opportunity to examine the relationships of native and exotic plants to varying management regimes across the agricultural landscape. The results were used to assess the effects of grazing by sheep and cattle, fertilisation and the introduction of exotic pasture species to the grassy communities.

2.1.1 Chapter aims

The aims of the chapter are to determine:

- the types of pastures that are present;
- the environmental and management factors that are associated with these pastures; and
- the environmental and management factors that are associated with the abundance of species, genera, major taxonomic groups of plants and life-form groups.

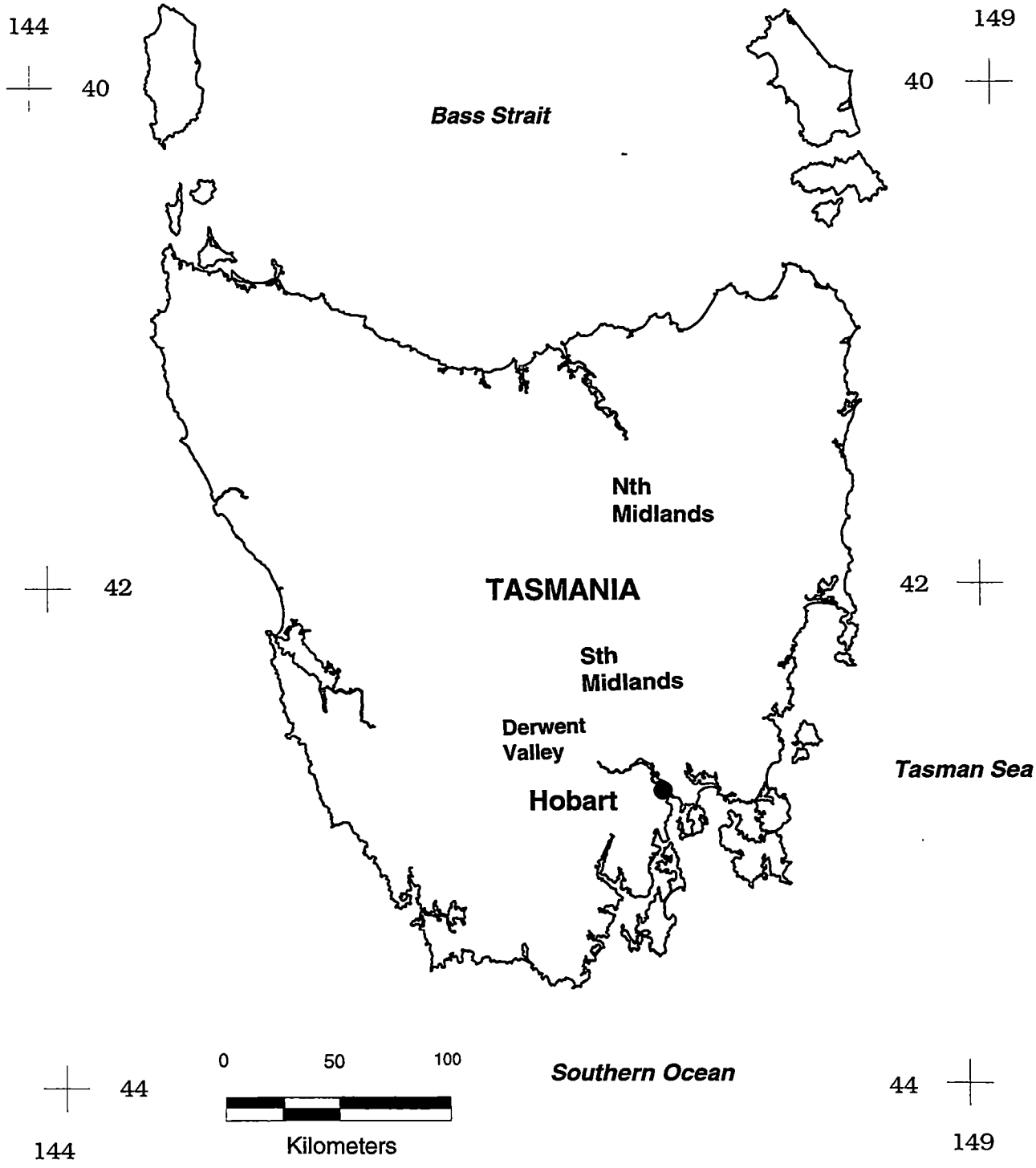

Fig. 2.1. Map of Tasmania showing study areas

2.2 Methods

2.2.1 Field survey and interviews with land managers

A total of 354 paddocks on 98 properties were sampled between September 1992 and January 1993. Figs 2.2-2.5 show scenes representing some of the variation of the study area. Stratified random sampling was used to determine the properties and paddocks which were sampled.

The dry lowland areas of Tasmania have been described in terms of a land systems analysis (Davies 1988). The land system classification is based on the rainfall, topographical and geological characteristics of the area, which influence the development of soils and vegetation.

Land systems that were present within the study areas were determined and properties were randomly selected from within these land systems. For each of these properties, an interview was carried out with the land holder or land manager and a number of paddocks were selected for sampling. The term paddock is used to refer to a fenced area that is treated as a grazing management unit. This can include small blocks or large bush runs in rough country.

The number of paddocks in each sampled property was determined according to the size and heterogeneity of the property. Between 3 and 6 paddocks were randomly selected from these to represent the variation within the property.

Within each paddock a 100 m x 100 m (1 ha) area was randomly selected. The selected area was rejected if the vegetation was not considered to be representative of the paddock as a whole. The selected sites were also rejected if the cover of taller plants, which would constitute a midstorey in native vegetation, was greater than approximately 30% of the area.

Fig. 2.2. View of *Themeda triandra* grassy woodland in the Tunbridge area, Midlands

Fig. 2.3. View *Poa labillardierei* tussock grassland in valley flat, Nile area

Fig. 2.4. Looking across improved pastures with Eastern Tiers in the distance, Tunbridge area

Fig. 2.5. Unimproved native pasture on left and improved pasture on right of fence

In the interview which was conducted with the land holder or land manager questions were asked concerning the management of the whole property and the paddocks selected for sampling. Data on soil, geology, geomorphology and vegetation were collected and soil samples were collected for laboratory chemical testing.

Management information collected for the whole property included:

- the proportion of the property devoted to cropping, improved pasture, unimproved pasture and bush;
- the types of animal enterprises run on the property; and
- the overall numbers of the different types of stock grazed on the property.

Management information collected for each paddock, including paddocks sown to improve pasture species, included:

- the method of sowing and the occurrence of ploughing;
- the date of last sowing;
- the species sown, the method of sowing and the sowing rate;
- the use of a herbicide prior to sowing;
- the sowing of additional seed following the main seeding event;
- the types and rates of sowing of fertiliser applied since sowing;
- history of sowing and fertilising before sowing;
- what types of stock had been grazing the area; and
- the type of seasonal grazing management, either set stocking or rotational grazing and spelling of paddocks.

Other questions concerned:

- whether the paddocks had been cut for fodder conservation (hay or silage);
- the incidence of grass grubs and other pests;
- the incidence of weeds; and
- the use of control methods for pests or weeds.

For native pastures many of the above questions were not applicable and the questions asked in this case included:

- the number of years over which the areas had been grazed;
- the use of burning as a management tool;
- the year and season of the last burn;
- the incidence of scrub clearing; and
- whether any changes had been detected over time by the landholder/manager.

Soil, geological and geomorphological information collected included:

- aspect, slope, landform element;
- the degree and type of erosion;
- the abundance and size of surface rock fragments;
- the presence of rock outcrops;
- the texture, colour and depth of A and B soil horizons; and
- the presence and depth of a compact layer (a hard clay layer or bedrock).

Thirty soil samples were collected using a soil corer of 2 cm diameter that took soil cores to a depth of 7.5 cm. The soil cores were bagged, bulked and then sub-sampled for the soil chemical tests. Soils were tested for pH (water and $CaCl_2$ tests), salinity, extractable phosphorus, extractable potassium and soil organic carbon. All tests were as in Rayment and Higginson (1992).

At each site the following data was collected:

- in three quadrats measuring 5 m x 1 m, the cover on the Braun-Blanquet scale (Mueller-Dombois and Ellenberg 1974), of all vascular plant species that were identifiable, the cover of sown perennial grasses, native perennial grasses, clovers (sown and adventitious legumes), species regarded as valuable grazing species (sown perennial grasses, native perennial grasses and clovers), annual exotic grasses, total exotic weeds, the sum of species which have been sown, bare ground, litter, rock and moss;

- a visual estimate of pasture height over the 1 ha area;
- a list of tree species present and cover on the scale of isolated, very sparse (< 2%) and sparse (< 5%) over the 1 ha; and
- a list of plant species forming a midstorey with the cover of the midstorey estimated on the B-B scale for the whole 1 ha.

2.2.2 Analysis of data

Data were entered into the ecological database program, DECODA (ANUTECH Pty Ltd, Australian National University, Canberra). Some plant species were not able to be identified to species level over the duration of the survey due to a lack of flowering and seeding material, especially in early spring. These species were commonly aggregated to the genus level and the cover abundance value on the B-B scale was determined in the field. The mid-points of the B-B classes were used to calculate percentage cover abundance values.

The genera into which the species were aggregated are listed in Appendix 1. Some specimens in the field were classified only to the level of family or to a higher level taxonomic group. The higher level groups included Dicotyledons, Monocotyledons, Orchidaceae, Cyperaceae and Pteridophytes.

The sums of the cover values all species belonging to the Raunkiaer life-form classification (Raunkiaer 1934) were determined. Along with the four sub-classes of the hemicryptophyte class, a fifth class, caespitose hemicryptophytes was used (Table 2.1). Caespitose hemicryptophytes are defined as species that form distinct tussocks that give protection to internal, near-ground level buds. Determination of life-form classification were by observations of persistent buds, morphology and growth form throughout the year.

Table 2.1. Descriptions of life-forms, life-history and morphological attributes of species, used to classify the species found in the survey based on Raunkiaer (1934). The caespitose sub-class of the hemicryptophyte group was added

Life-forms are:

- therophytes, predominantly annual plants — however some may be perennial in some conditions;
- chamaephytes, perennial plants with the lowest buds ≥ 1 cm and < 20 – 30 cm above soil surface;
- geophytes, perennial plants with persistent buds ≥ 2 cm below soil surface;
- hemicryptophytes, perennial plants with lowest persistent buds at soil surface, < 2 cm below and < 1 cm above;

hemicryptophytes are divided into:

- flat or versatile rosette, all leaves are radical, predominantly flat but can be erect depending on height of surrounding vegetation;
- erect rosette, all leaves radical but not caespitose;
- partial rosette, leaves radical and cauline, largest leaves toward bottom of stem;
- proto-hemicryptophytes, all leaves cauline, largest leaves toward middle of the stem;
- caespitose hemicryptophytes, which form a tuft or tussock providing protection to growing shoots;

phanerophytes, plants with persistent buds more than 20 – 30 cm above ground level.

2.2.3 Sites grouped by proportion of exotic species compared to total cover

The total cover of life-form groups, and native and exotic species within the life-form groups, was determined. Total, native and exotic species richness values were determined, based on the above aggregated taxa. The total cover of all exotic species was determined and was divided by the total plant cover and referred to as exotic/total cover. As total cover can vary greatly the exotic species cover in relation to total cover is a more meaningful measure than exotic cover alone. The sites were placed into 27

groups according to exotic/total cover. The upper limits of exotic/total cover for the groups were chosen to limit variation in the number of samples placed into the groups.

The frequencies of taxa in the samples of the 27 groups were determined using DECODA. The proportions of unsown, aerially sown and cultivated and sown paddocks in the groups were also determined. The mean times since the sites were sown or fertilised was determined from the management information collected in the interviews. In some cases, the time since the last fertilisation or sowing of the pasture was not known. For these sites missing values were recorded.

The mean values of total, native and exotic species richness, sown perennial grasses, native perennial grasses, clovers, species regarded as valuable grazing species, annual weedy grasses, total exotic weeds, total species that had been sown, bare ground, litter, rock and moss were determined for each group. The mean values of the cover of native and exotic species belonging to the life-form classifications were also determined.

2.2.4 Sites grouped by management regimes, phosphorus level and broad habitat classes

Differences in the levels of individual species, genera and life-forms were analysed between different types of sowing regimes, levels of phosphorus and broad habitat types.

The sowing regime for each site was categorised as one of three classes:

1. sites not known to have been sown or fertilised,

2. sites which had been sown with grass or legume seed, but without cultivation or direct drilling — this usually involved surface sowing of grass and legume seed from an aeroplane or tractor, and is referred to as aerial sowing;

3. sites that had been sown with introduced pasture species, which involved either cultivation or herbiciding. Direct drilled sites were assumed to have been herbicided before sowing. Usually these sites had been sown and cultivated at an earlier date.

Phosphorus is generally regarded as the main limiting factor in the growth of improved pasture species in Tasmania (Nicholls and Dimmock 1965), and was therefore used as an indicator of fertility in analysis. The level of soil phosphorus was classified as low, medium or high, where low was ≤ 15 ppm, medium was > 15 ppm but ≤ 35 ppm, and high was > 35 ppm. The cut-off values of the levels of soil phosphorus used to classify the samples were chosen to divide the samples into 3 approximately equal groups.

Nitrogen is another important nutrient. However, it was not measured. The cover of legumes was regarded as an indicator of the amount of available nitrogen. This assumption is generally regarded to be reasonable. However, in some cases this may not be true. Legumes may gain a competitive advantage over other species in areas of low nitrogen by the fixation of nitrogen (Towne and Knapp 1996).

Low or high pH, salinity, potassium and various trace elements may also have affected species growth.

The sites were classified into broad habitat classes based on geological substrate and annual rainfall. The habitat classes were:

1. igneous substrate, annual rainfall below 600 mm/yr,
2. igneous substrate, annual rainfall above 600 mm/yr,
3. sedimentary substrate, annual rainfall below 600 mm/yr,
4. sedimentary substrate, annual rainfall above 600 mm/yr,
5. alluvial substrate (almost all sites were below 600 mm/yr, rainfall).

The sample variable data and the percentage cover values of all taxa were entered into the SAS statistical program (SAS 1989). The differences in mean abundance of the species, taxa and life-forms between pairs of the combinations of the sowing regime, phosphorus level and habitat were determined. There were 45 possible combinations of 5 types of habitat, the 3 types of sowing regime and the 3 levels of phosphorus. The numbers of samples in those groups were highly non-orthogonal and varied between 0 and 62. Combination of groups with low sample size and similar characteristics resulted in 20 consolidated groups (Table 2.2), which were used in the subsequent analysis.

Table 2.2. Characteristics of groups of sites based on sowing regime, level of phosphorus, geological substrate and rainfall

Unsown

Group 1: low phosphorus, dolerite substrate

Group 2: low phosphorus, sedimentary substrate

Group 3: medium to high phosphorus, igneous substrate

Aerially sown/uncultivated

Group 4: low phosphorus, mainly igneous substrate (also sedimentary)

Group 5: medium to high phosphorus, mainly igneous substrate (also some sites with sedimentary substrates)

Sown/cultivated

Group 6: low phosphorus, igneous, rainfall < 600 mm/yr

Group 7: low phosphorus, igneous, rainfall > 600 mm/yr

Group 8: low phosphorus, sedimentary, rainfall < 600 mm/yr

Group 9: low phosphorus, sedimentary, rainfall > 600 mm/yr

Group 10: medium phosphorus, igneous, rainfall < 600 mm/yr

Group 11: medium phosphorus, igneous, rainfall > 600 mm/yr

Group 12: medium phosphorus, sedimentary, rainfall < 600 mm/yr

Group 13: medium phosphorus, sedimentary, rainfall > 600 mm/yr

Group 14: low to medium phosphorus, alluvial substrate

Group 15: high phosphorus, igneous, rainfall < 600 mm/yr

Group 16: high phosphorus, igneous, rainfall > 600 mm/yr

Group 17: high phosphorus, sedimentary, rainfall < 600 mm/yr

Group 18: high phosphorus, sedimentary, rainfall > 600 mm/yr

Group 19: high phosphorus, alluvial substrates

Ungrouped

Group 20: ungrouped, contain missing data

Analysis of the degree of similarity of species composition within groups

Discriminant function analysis was used to determine whether the vegetation of the sites was different between the above groups. The group to which each sample was assigned was entered as a variable. The CANDISC function of SAS (SAS 1989) was used to determine whether the vegetation differed significantly between the 20 consolidated groups.

The CANDISC function used cluster analysis to sort the samples into 20 groups on the basis of the co-occurrences of all 212 species and taxa. Then a cross-validation table was constructed where the groups described by sowing regime, level of phosphorus, geological substrate and rainfall and the groups into which the sites were sorted by the discriminant function, were listed as the x and y axes of a table, respectively. The level of correspondence between the groups described by sowing regime, level of phosphorus, geological substrate and rainfall, and the groups into which the sites were sorted, was indicated as a percentage.

General linear models (GLM) were used to examine the cover abundance data for the species, genera and life-forms between the 20 groups. The SAS statistical package was used to generate GLM from the untransformed, log transformed and square root transformed percentage cover abundance values of the species or life-form group. Native species that were found in 30 or more of the samples and exotic species that were found in 40 or more of the samples were tested. *Phalaris aquatica* was also tested since it is sown as a pasture species.

The transformed values were calculated using the following equations:

1. logarithmic transformation:

$$\log_{10}(\text{species}) = \log_{10}(\%\ \text{cover} + 1)$$

2. square root transformation:

$$\text{square root (species)} = \text{square root}(\%\ \text{cover} + 0.5)$$

Tests for normality of the untransformed and transformed species data were conducted. In addition, the major assumptions that were made when using GLM were checked by

plotting standardised residuals and cumulative probability curves as described in McPherson (1990).

An F test in the GLM procedure was used to test for overall significant differences in least squares means (SAS 1989). The transformation or non transformation that both conformed with the tests for normality and resulted in the F test with the lowest probability was used to examine differences between pairs of groups.

In cases where the F test did not indicate significant differences overall between group least-squares means it is still possible that there are significant differences between pairs of means. Multiple comparisons of groups that were pre-determined to be of interest were made using unrestricted least significant difference (LSD) or multiple t test as recommended by Saville (1990). The significance of an overall F test is not required for the unrestricted LSD to be determined (Saville 1990).

Multiple comparison procedures have been the subject of considerable controversy among statisticians, see for example Saville (1990, 1991), Holland (1991) and Lea (1991). The unrestricted least significant difference is recommended as it has the maximum power compared with other multiple comparison procedures and is simple, consistent and easy to calculate (Saville 1990)

Abundance of taxa and life-form groups related to levels of phosphorus

The response of taxa or life-form groups to the level of phosphorus was determined by the significance of differences in cover between a pair of groups that differed in the phosphorus level only. Estimations of the responses to phosphorus in unsown and aerially sown pastures were based on high rainfall sites on dolerite. The effects of the level of phosphorus in sown pastures were determined with all substrates and between low, medium and high levels of phosphorus. A schematic representation of the characteristics of the groups is presented in Table 2.3.

The responses to phosphorus level were determined:

- for unsown pastures (between groups 1 and 3), and
- for aerially sown pastures (between groups 4 and 5),

- for sown pastures (between groups 6 and 10, 7 and 11, 8 and 12, 9 and 13, 10 and 15, 11 and 16, 12 and 17, 13 and 18, and 14 and 19).

For sown pastures, if the number of increases was greater than or equal to the numbers of decreases, the species were listed as increasing with phosphorus in sown pastures. If the number of decreases was greater than or equal to the number of increases, the species were listed as decreasing.

Table 2.3. Groups of samples with combinations of sowing regime, phosphorus level and geological substrate and rainfall. Where a group includes more than one combination of the factors, the position of the group number indicates the most common combination. N = number of samples in the group. Rf = rainfall, sedim = sedimentary and P = phosphorus

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 n=42		2 n=9	
unsown med P		3 n=9			
unsown high P					
aerial low P		4 n=14			
aerial med P		5 n=10			
aerial high P					
sown low P	6 n=12	7 n=13	8 n=10	9 n=19	
sown med P	10 n=16	11 n=16	12 n=22	13 n=62	14 n=13
sown high P	15 n=13	16 n=9	17 n=13	18 n=27	19 n=15

Group 20 = ungrouped n=10

Abundance of taxa and life-form groups related to sowing regimes

The responses of taxa and life-form groups to differences in the sowing regime were determined for groups in high rainfall sites on igneous substrates.

The responses to aerial sowing were determined from the difference between groups 1 and 4, and 3 and 5. The effects of cultivation were determined from the difference between either groups 4 and 7 or 5 and 11.

The effects of sowing, that is the cultivation, fertilisation and sowing of seed, were determined from the differences between groups 1 and 7, 2 and 9, and 3 and 11.

Abundance of taxa and life-form groups related to geological substrates

The levels of taxa and life-form groups for different geological substrates were determined for unsown pastures and sown pastures. For the unsown pastures, the difference was determined between groups 1 and 2. For sown pastures, the difference was determined between either groups 6 and 8 or 7 and 9. If an exotic species was not present in unsown pastures or a native species was not present in sown pasture then that species was recorded as not changing in those pastures.

Abundance of taxa and life-form groups related to rainfall on sown pastures

The differences in the level of taxa and life-form groups with rainfall were determined by the comparison of groups 6 and 7, 8 and 9, 10 and 11, and 12 and 13. If one or more of the differences in cover between these groups was significant then the species, genus or life-form was taken to have been different with different rainfall. The comparison was only possible with sown pastures with low to medium phosphorus levels.

2.3 Results

2.3.1 The flora and characteristics of sites

A total of 215 higher plant species and aggregated taxa were recorded (Table 2.4, see also Appendix 1). The most represented families were Poaceae and Asteraceae, with lesser numbers of Caryophyllaceae, Fabaceae, Apiaceae, Epacridaceae, Geraniaceae, Rosaceae, Cyperaceae, Juncaceae and Liliaceae.

Table 2.4. Number of native and exotic species in modified Raunkiaer life-forms (Raunkiaer 1934)

Life-form/subclass	Native	Exotic	Total
Therophytes	13	50	63
Chamaephytes	14	1	15
Geophytes	6	1	7
Hemicryptophytes			
Flat/versatile rosette	11	9	20
Erect rosette	19	9	28
Partial rosette	6	3	9
Proto-hemicryptophytes	6	2	8
Caespitose	15	9	24
Phanerophytes	11	2	13
Unassigned	1	9	10
Total	102	95	197

The most represented life-forms were therophytes, most of which were introduced species, then erect rosette hemicryptophytes, which were dominated by native species, flat/versatile rosette hemicryptophytes, with equal numbers of native and exotic species, and native chamaephytes (Table 2.4).

Unsown sites accounted for 17% of all sites and were located mainly on igneous substrates with a high mean altitude and rainfall and were on steep slopes. Aerially sown sites were 6.5% of all sites and were mainly located on igneous substrates at high altitudes and steep slopes. The remaining 75% of sites were sown with 30% on igneous substrates, 59% on sedimentary substrates and 11% on alluvial substrates. These were at lower altitudes and on shallower slopes (Table 2.5). The numbers of sown sites with

alluvial and sedimentary substrates compared to unsown sites on those substrates reflects the preferential cultivation of those soil types.

Levels of phosphorus were lowest on unsown sites and the levels for igneous and sedimentary substrates were similar. Potassium was higher on igneous substrates. Levels of phosphorus and potassium were higher on aerially sown sites (Table 2.5).

Table 2.5. Means and standard deviations of altitude, slope, rainfall and soil characteristics of unsown, aerially sown and cultivated and sown sites on igneous, sedimentary and alluvial sites

	N	Altitude (m)	Rainfall (mm/yr)	Slope (^{0})	pH (water)	Salinity (% NaCl)
Unsown/igneous	51	381.0±94.4	680.6±88.6	8.39±5.75	6.01±0.26	0.071±0.022
Unsown/sedimentary	9	332.2±105.6	612.8±57.4	9.67±8.59	5.88±0.29	0.071±0.025
Aerial/igneous	21	373.8±91.2	634.8±49.9	8.00±6.07	6.02±0.27	0.089±0.025
Sown/igneous	80	284.3±104.1	619.1±70.7	3.98±3.63	5.85±0.30	0.116±0.077
Sown/sedimentary	157	278.5±125.4	642.0±87.6	2.43±3.48	5.71±0.30	0.095±0.034
Sown/alluvial	30	225.2±73.9	558.3±21.4	1.83±3.61	5.75±0.28	0.116±0.057

	Phosphorus (ppm)	Potassium (ppm)	Organic matter (% C)	Time since last sown (years)
Unsown/igneous	11.45±14.18	337±142	5.54±1.73	
Unsown/sedimentary	11.56±7.75	291±185	5.38±2.25	
Aerial/igneous	17.95±10.10	389±134	6.77±1.62	17.43±11.72
Sown/igneous	27.78±18.53	298±153	5.06±1.72	11.67±12.00
Sown/sedimentary	29.38±17.90	274±140	4.36±1.42	7.40±4.64
Sown/alluvial	39.07±19.55	269±110	4.03±1.78	7.43±4.47

The level of phosphorus (P), but not potassium, was higher on sown sites than aerially sown sites and higher on sedimentary and alluvial substrates than on igneous substrates. The time since sowing was longer for sites on igneous substrates than other sites, and this corresponded with lower P values (Table 2.5).

Times since last sowing were least for sown sites on sedimentary and alluvial substrates, and less than sown sites on igneous substrates (Table 2.5).

2.3.2 Sites grouped by proportion of exotic species compared to total cover

The level of exotic species cover compared to the total was related to the proportion of sown sites (Fig. 2.6). Native species richness was closely related to the proportion of unsown sites (Table 2.6). The 21 sites with the least exotic species cover had a mean of 27.4 native species/m^2. Native species richness was high where exotic cover was less than 20% of the total (Fig. 2.7), however, above that level it decreased rapidly. Exotic species richness increased steadily from a mean low of 5 species/m^2, in the least invaded pastures, and reached its maximum level when exotic/total cover was approximately 50% (Fig. 2.7). Phosphorus and potassium tended to be higher with higher exotic/total cover (Figs. 2.8 and 2.9).

Native life-form groups with the greatest persistence in pastures where exotic/total cover was high were caespitose hemicryptophytes, flat/versatile and erect rosette hemicryptophytes (Table 2.7). Within these life-form groups the persistence of the species varied. Species in the erect rosette and caespitose hemicryptophyte groups had moderate to high tolerance of improved pasture conditions. Flat versatile rosette hemicryptophytes generally had moderate tolerance (Table 2.8).

The native chamaephyte life-form group had the lowest persistence (Tables 2.6 and 2.8). The two species of this group that were persistent, *Asperula conferta* and *Acaena novae-zelandiae* (Table 2.8), had prostrate or subterranean growth. Therophytes, partial rosette and proto-hemicryptophytes were moderately persistent. Two native therophytes of low stature, *Crassula sieberana* and *Rutidosus multiflora,* were very persistent (Table 2.8).

Table 2.6. Groups of sites with upper limits of exotic/total cover, number of samples, native and exotic species richness, percentages of groups which have been aerially sown, sown or left unsown, and the mean time since sites were last sown or fertilised. na = not applicable

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Exotic/total cover upper class limit (%)	4	6	10	14	19	23	30	40	46	50	58	62	70	72	76	80	84	88	94	95	97	98	98.5	99	99.5	99.75	100
Number of sites	5	4	6	6	6	8	5	6	5	7	7	8	7	7	8	8	9	6	5	7	7	8	10	11	19	26	143
Native species richness	23.6	28.3	27.2	30.3	24.3	27.3	22.4	25.0	20.4	17.9	18.0	16.4	8.9	7.0	10.4	7.1	7.1	7.2	5.8	5.6	5.1	3.1	2.8	2.6	2.4	1.6	0.3
Exotic species richness	5.0	6.8	9.3	11.8	9.7	12.8	14.8	13.2	15.6	17.0	17.3	18.9	14.0	17.1	19.9	18.0	16.8	19.7	17.4	16.3	16.9	15.9	16.2	17.8	17.2	17.4	16.1
Unsown sites (%)	100.0	100.0	83.3	66.7	100.0	100.0	100.0	50.0	60.0	57.1	42.9	25.0	0.0	0.0	37.5	0.0	22.2	16.7	0.0	0.0	0.0	0.0	0.0	9.1	0.0	0.0	0.0
Aerially sown sites (%)	0.0	0.0	0.0	33.3	0.0	0.0	0.0	33.3	20.0	42.9	42.9	12.5	28.6	0.0	37.5	12.5	11.1	33.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.7	0.0
Mean age aerially sown sites (yrs)	na	na	na	11.0	na	na	na	10.5	20.0	20.3	12.3	4.0	15.5	na	9.3	32.0	24.0	25.5	na	na	na	na	na	na	na	35.0	na
Sown sites (%)	0.0	0.0	16.7	0.0	0.0	0.0	0.0	16.7	20.0	0.0	14.3	62.5	71.4	85.7	25.0	75.0	66.7	50.0	100.0	100.0	100.0	100.0	100.0	90.9	100.0	88.5	99.3
Mean age sown sites	na	na	11.0	na	na	na	na	2.0	11.0	na	na	17.2	11.0	8.8	20.5	5.4	10.3	8.3	14.7	7.8	13.7	9.1	7.9	7.0	12.7	8.6	7.4
Sites with history unknown (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.3	0.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.9	0.7

Table 2.7. Groups of sites as for Table 2.6 with mean values of cover of native and exotic species in life-forms, groups of species and site variables. Hemis = hemicryptophytes.

Group number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Native																											
Therophytes	0.5	0.1	0.5	1.0	0.5	1.3	2.8	0.4	0.3	0.2	0.2	0.5	0.5	0.3	0.2	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0
Chamaephytes	6.9	6.1	2.8	2.3	0.7	2.4	2.5	2.1	1.1	0.6	0.3	1.3	0.3	0.3	0.1	0.2	0.2	0.6	0.1	1.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Geophytes	0.1	0.1	0.1	0.0	0.1	0.0	0.1	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Flat/vers rosette hemis	15.8	3.8	4.2	9.5	9.1	6.8	9.4	8.3	25.5	7.6	10.7	3.1	0.8	0.6	3.4	0.6	2.5	3.3	1.2	0.2	0.6	0.1	0.2	0.1	0.1	0.1	0.0
Erect rosette hemis	14.1	16.5	21.6	17.2	11.1	14.9	17.8	13.2	9.9	6.4	8.2	17.5	9.2	8.2	4.9	3.5	7.5	3.8	2.7	2.1	1.9	1.1	0.8	0.9	0.3	0.1	0.0
Partial rosette hemis	0.4	0.3	2.9	1.7	0.2	0.7	0.3	0.9	0.0	1.0	0.4	0.6	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Proto-hemis	2.1	1.8	2.6	1.6	1.1	2.3	1.0	1.7	3.8	1.3	1.6	0.6	0.2	0.0	0.2	0.4	0.0	0.1	0.2	0.1	0.0	0.0	0.1	0.1	0.1	0.0	0.0
Caespitose hemis	27.9	32.6	36.4	47.6	38.2	35.3	40.3	27.9	19.3	40.7	30.3	29.3	25.4	21.5	18.4	17.5	9.5	7.4	2.6	1.7	0.7	1.2	0.6	0.2	0.1	0.1	0.0
Phanerophyte	0.2	0.0	0.2	0.1	0.6	2.2	0.0	11.8	0.0	0.0	0.1	6.3	1.5	0.4	6.3	0.0	0.0	0.0	0.7	0.0	0.0	0.1	0.0	0.1	0.3	0.0	0.0
Exotic																											
Therophytes	0.7	1.5	2.1	5.1	3.6	5.5	8.9	11.4	22.7	28.5	36.3	39.2	44.4	47.9	46.5	52.5	59.7	51.2	51.3	64.9	66.1	74.3	73.3	57.2	64.8	60.6	67.2
Chamaephytes	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Flat/vers rosette hemis	0.8	1.7	3.5	3.7	5.4	9.7	11.5	6.8	14.4	21.4	15.7	18.5	15.5	9.1	10.4	12.3	18.6	17.5	19.7	22.6	12.6	6.5	12.6	14.0	9.0	13.2	11.7
Erect rosette hemis	0.0	0.0	0.0	0.0	0.0	0.2	6.5	2.2	3.6	1.1	2.8	5.2	2.1	3.2	4.6	2.5	8.4	5.2	16.8	1.3	4.4	10.3	4.9	2.0	6.1	5.7	7.2
Partial rosette hemis	0.0	0.0	0.0	0.1	0.5	0.0	0.1	0.3	0.0	0.3	0.6	2.3	0.3	0.8	0.4	0.8	1.1	0.3	0.2	0.6	1.3	1.5	2.0	2.0	0.5	0.5	0.9
Proto-hemis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.6	0.0	0.1	0.0
Caespitose hemis	0.0	0.1	0.0	1.6	1.7	0.2	2.6	0.1	7.6	2.9	2.4	8.4	7.2	14.0	14.5	14.2	9.8	21.2	20.3	22.1	13.7	13.3	21.8	31.9	21.8	26.7	28.9

Table continued next page.

Table 2.7. Continued from previous page

Group number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Sown perennial grass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.3	1.0	4.5	4.6	8.6	9.1	12.3	5.7	16.6	13.4	14.9	9.9	11.9	18.3	30.2	17.7	24.1	26.8
Native perennial grass	41.8	30.9	33.3	39.1	42.7	39.0	36.2	37.2	43.2	48.7	39.8	31.5	26.3	24.6	23.9	16.2	9.8	9.3	3.7	5.0	0.7	1.7	0.6	0.1	0.1	0.1	0.0
Clovers	0.1	3.6	0.5	1.7	0.5	2.1	2.6	4.1	14.2	18.0	25.1	25.2	27.4	30.0	32.3	36.9	46.5	39.7	42.2	51.7	47.0	50.3	44.9	58.2	50.6	50.5	53.0
Valuable grazing species	32.7	34.9	34.9	38.4	38.9	33.3	37.0	36.4	47.1	55.2	59.7	52.5	42.3	47.4	47.4	55.0	51.4	60.2	56.4	55.3	45.4	54.1	52.7	74.7	57.3	60.6	63.2
Annual weedy grasses	0.1	0.6	0.5	2.7	1.5	2.2	5.1	1.9	6.7	2.7	9.3	11.2	13.6	12.0	10.0	16.6	22.3	14.6	14.1	12.1	17.6	13.2	22.6	14.3	14.7	13.7	15.9
Total exotic weeds	0.6	1.3	3.1	4.8	6.8	10.3	17.5	12.1	24.6	22.9	29.7	31.2	24.5	29.8	22.6	23.9	32.1	28.2	44.2	32.1	22.2	19.9	42.1	21.9	33.4	24.9	24.4
Total plant cover	47.1	58.8	67.2	65.9	69.6	66.5	74.7	68.6	83.3	89.8	88.3	85.7	80.7	88.8	80.5	85.4	91.4	90.7	95.0	89.1	89.5	91.6	97.9	96.3	91.7	93.1	92.8
Bare ground	9.2	25.9	21.6	13.3	15.3	15.4	9.7	23.7	1.8	8.2	5.0	10.8	15.7	3.7	1.7	8.1	1.8	4.8	1.3	5.8	7.8	4.5	0.8	1.1	3.0	4.8	1.5
Litter	33.9	12.6	9.3	13.0	13.6	11.1	13.0	5.7	10.5	3.3	7.3	2.3	3.9	2.4	3.7	4.1	3.1	3.9	2.5	0.7	2.8	1.0	0.8	0.7	2.0	2.6	1.6
Rock	1.7	4.6	6.7	8.5	4.3	3.7	5.0	2.8	2.0	2.0	8.4	3.6	2.9	2.2	1.5	1.4	1.4	0.4	1.1	0.2	0.0	0.2	0.2	0.8	0.4	0.7	0.2
Moss	9.0	2.2	3.1	3.4	10.8	8.5	11.3	6.7	3.6	1.8	1.9	6.5	0.9	1.4	2.6	1.0	1.5	0.3	0.8	0.5	0.5	0.3	0.6	0.1	0.5	0.3	0.1
Altitude	346	393	343	373	383	341	398	291	330	326	350	278	317	340	329	364	341	302	338	254	217	281	303	326	287	279	269
Rainfall (mm/yr)	739	689	723	671	644	631	705	651	667	608	602	619	594	604	643	569	640	657	623	582	606	642	678	608	621	612	626
Slope (degrees)	7.4	8.3	5.0	5.3	9.7	8.1	4.2	6.5	4.4	8.1	10.6	7.9	6.4	6.4	7.3	6.7	4.1	3.3	6.0	6.0	4.1	5.6	2.5	2.8	3.6	6.2	2.3
pH (water)	5.8	5.7	5.9	5.9	5.7	5.9	5.7	5.8	5.8	6.0	5.8	6.0	5.8	5.9	5.9	5.9	5.9	5.8	5.9	5.7	5.8	5.6	5.7	6.0	5.8	5.8	5.8
pH (calcium)	5.2	5.2	5.5	5.4	5.1	5.3	5.1	5.2	5.2	5.5	5.2	5.5	5.3	5.3	5.3	5.5	5.3	5.2	5.4	5.1	5.1	5.1	5.1	5.2	5.2	5.3	5.2
Salinity	0.092	0.103	0.083	0.098	0.072	0.085	0.086	0.082	0.074	0.07	0.091	0.088	0.076	0.067	0.101	0.146	0.074	0.103	0.096	0.091	0.096	0.105	0.108	0.098	0.082	0.104	0.105
Phosphorus	10.4	27	10	16.5	18.5	14.4	23	19	18	12	28.7	14.9	15.6	23.4	27.8	33.5	15.8	33.5	27.2	20.1	26	21.8	12.7	31.7	23	35.7	34.3
Potassium	267	287	223	322	230	335	295	266	282	322	350	401	335	339	353	330	308	237	422	308	298	246	282	312	208	280	286
Organic matter	5.1	5.4	4.1	5.6	4.2	5.2	4.4	4.3	7.0	5.4	5.7	5.0	5.1	4.5	5.9	5.4	5.2	5.5	6.0	4.9	5.0	3.4	4.5	4.5	4.7	4.9	4.4

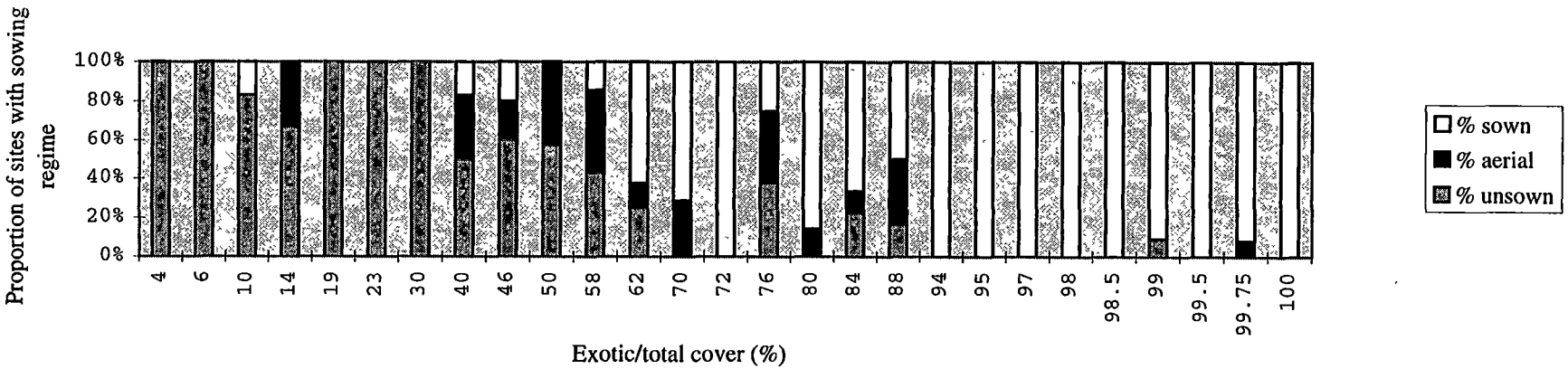

Fig. 2.6. Proportion of site with sowing regimes in groups of sites classified according to exotic/total cover

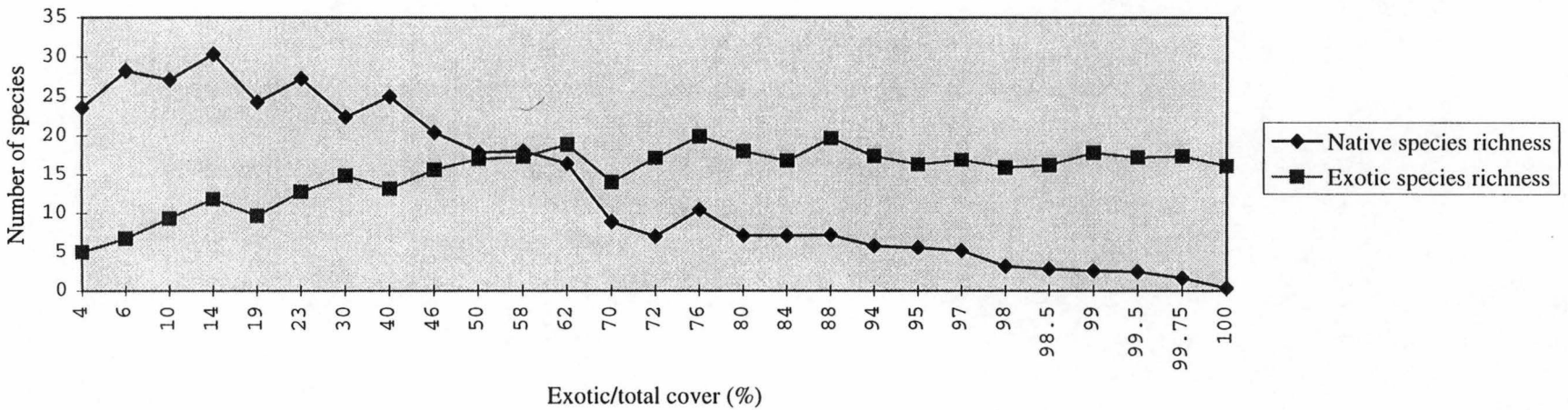

Fig. 2.7. Native and exotic species richness in groups of sites classified according to exotic/total cover

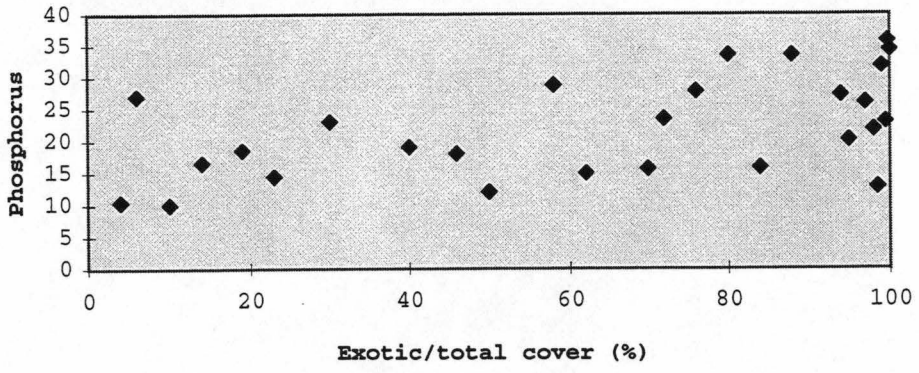

Fig. 2.8. Mean levels of phosphorus in groups of sites classified according to exotic/total cover

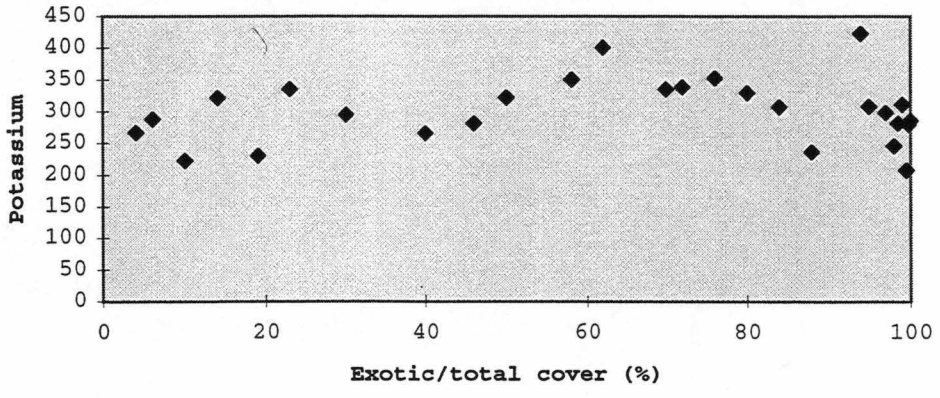

Fig. 2.9. Mean levels of potassium in groups of sites classified according to exotic/total cover

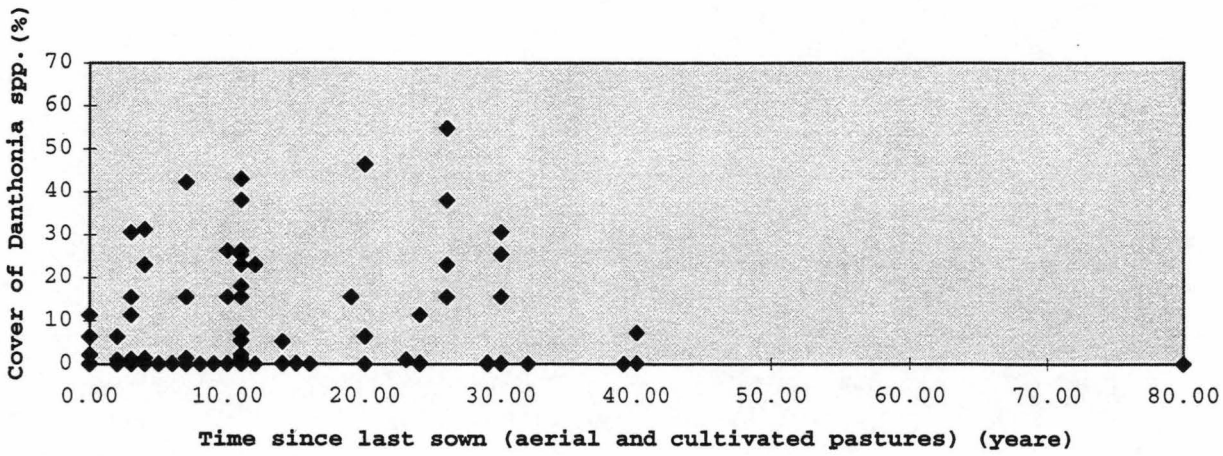

Fig. 2.10. Cover of *Danthonia* spp. against time since last sown for aerially sown and sown pastures

Table 2.8. Table of classes of mean cover of taxa in groups of sites with upper class limits of exotic/total cover. Only taxa present in five or more sites are included. The upper limits of the groups are as in Table 2.6. The classes of mean cover of taxa are: 1 = 1%, 2 = 3%, 3 = 5%, 4 = 10%, 5 = 15%, 6 = 20%, 7 = 30%, 8 = 40% and 9 = 50%

	1111111111222222222
	123456789012345678901234567
Native therophytes	
Aphelia pumilio	1--111-1------------------
Cotula australis	111111211111--11-------1---
Crassula sieberiana	--11-11111111111-1--11-1-11
Cyperus tenellus	----1---1--1---------------
Daucus glochidiatus	--11111-----1-------------
Hydrocotyle callicarpa	111111111--1--1------------
Poranthera microphylla	1--1111-1------------------
Rutidosis multiflora	---1-1-1----11111---1---1--
Sebaea ovata	---111----1----------------
Exotic therophytes	
Aira caryophyllea	11121122123211212111211111
Anagallis arvensis	--1-11-1-1-1---1-----111111
Aphanes arvensis	11-1111111111111111111111
Arctotheca calendula	--------11-1132-12--1431211
Avena sativa	----------------------1----1
Briza minor	1111111111111111111-11-11
Bromus spp.(annual)	---11111112121232323333233
Calandrinia caulescens	--------------11----1--11-1
Capsella bursa-pastoris	1---1-----1----1--11--11111
Carduus spp.	----1-1-1111111211121-13222
Centaurium erythraea	111111111-11--1-----------1
Cerastium spp.	-11111111211121111111211111
Cicendia filiformis	-111-----111-1-------------
Cirsium vulgare	11111111211111111111111221
Cynosurus echinatus	---1-1-11122212112132121111
Erodium cicutarium	---1-11--1111111112111111111
Erodium moschatum	-------1-----11111-1-111111
Hordeum marinum	----------1-1111----12-1211
Hordeum murinum	-----1-1--1-111111222111123
Lolium multiflorum	--------1-111----111-111211
Moenchia erecta	1-1111111111111111111111111
Montia fontana	---1-11111-1111-11111111111
Myosotis discolor	-1-111111111-111-11-1111111
Parentucellia latifolia	--11-1-1111111211111--21111
Petrorhagia nanteuilii	---------1-1-1-----------1-
Poa annua	---11-111--1111111111211111
Sagina apetala	--11-11--111-111-------1--1
Silybum marianum	------------------------111
Sonchus oleraceus	-----1--------11--1---1-1-1
Spergula arvensis	--1--1-------1---1---1-1-11
Trifolium spp.	11121223556556566566554654454
Trifolium subterraneum	1-111-121435655765788888878
Vicia sativa	-----11-1----111-------1111
Vulpia spp.	-11121123123444464344554544

Table 2.8. Continued from previous page

Native chamaephytes	
Acaena novae-zelandiae	11-111211111111---1111--111
Asperula conferta	1111111111111--111-1----11-
Astroloma humifusum	111-11-11--1----1----------
Gonocarpus tetragynus	111-1--1---1----------------
Goodenia lanata	1--111-----1----------------
Hibbertia serpyllifolia	22211112--1----1---1-------
Lissanthe strigosa	211212111--1-------11------
Pimelea humilis	111111-1-111---1-----------
Scleranthus spp.	--11---1111111-11--------1-
Native geophytes	
Drosera peltata	111111112-11-111--11--1----
Orchidaceae spp.	1-11-11-111----1-----------
Pteridium esculentum	--12221----4-12-22--1-11---
Wurmbea dioica	111-1--111-1-1-----1-------
Native hemicryptophytes flat/versatile rosette	
Bossiaea prostrata	11111111-1-1-------1-------
Brachyscome spp.	11-111----------------------
Ehrharta stipoides	522343247342112-222-111----
Gnaphalium spp.	1111111112111-111-11--1---1
Hydrocotyle sibthorpioides	-112112----------------------
Oxalis perennans	1121112122111111112111111111
Pratia pedunculata	---1-1312-------------------
Ptilotus spathulatus	--11-1-1------1------------
Solenogyne dominii	111111111111111-11-11------
Solenogyne gunnii	1112111121211-1111--1------
Exotic hemicryptophytes flat/versatile rosette	
Bellis perennis	1--------------1---31---111
Hypochoeris radicata	12222444454432323344121222
Leontodon taraxacoides	11122231453433334323131222
Medicago spp.	--1--1--------12------1-111
Plantago coronopus	--11111112231121111221111
Plantago lanceolata	--1-11111212112134411111121
Taraxacum officinale	-11111-111-1-11111-11111111
Trifolium fragiferum	----------------------1111
Trifolium repens	---1--11-111213252342335444
Native hemicryptophytes erect rosette	
Acaena agnipila	--1-11--1111----1----------
Acaena echinata	11111111111111-111-11--1---
Acaena ovina	1111111111111--1-1---1-----
Arthropodium milleflorum	-11-11-11111--11-----------
Carex spp.	11111111211111111111111-1--
Hypoxis hygrometrica	111111-1-1-1-1-----1-------
Isolepis spp.	-11111111111211-1-111---111
Juncus spp.	11111111212222123111211111
Lepidosperma laterale	-11---13--1-----1--1-------
Plantago varia	1111111111111-11-----------
Veronica spp.	--1-1-11--1------1-------1-
Viola spp.	111211-1111--11-----------
Exotic hemicryptophytes erect rosette	
Agrostis capillaris	--1--12-3121222233413431434

Table 2.8. Continued from previous page

Native hemicryptophytes partial rosette	
Chrysocephalum spp.	111--1---1---1------11-----
Leptorhynchos squamatus	11221111-111111----1-------
Lomandra nana	-1111--1-1-1---------------
Luzula spp.	--111--11-11--1-1----------
Exotic hemicryptophytes partial rosette	
Acetosella vulgaris	---111111112111121-12222111
Rumex spp.	-----1---1--1-111-111111111
Native proto-hemicryptophytes	
Convolvulus erubescens	111111-1-1111--1--1-----1--
Dichondra repens	2121121121111----------1--
Geranium spp.	11111111111111111111-111111
Hypericum gramineum	111111111111---------------
Wahlenbergia spp.	-11111---1111---------1----
Native caespitose hemicryptophytes	
Danthonia spp.	5457657548777655431212111111
Dichelachne spp.	-1-1-1----11---------------
Elymus scabrus	-11-1211-113121221211-11---
Lomandra longifolia	1416422121121-12-1-11-111--
Poa labillardierei	13324453321123232321111-11-1
Poa rodwayi	4332331223211-1-1111---1-1-
Schoenus spp.	556544642343232-11111-11111
Stipa spp.	11111111132211111---1-1----
Themeda triandra	345444341222111-11-1-1-----
Exotic caespitose hemicryptophytes	
Agrostis stolonifera	---------------1--------1-1
Anthoxanthum odoratum	-----1221121----11311-12111
Cynosurus cristatus	------211-13-12-1241121-1-1
Dactylis glomerata	--1---1----2222411411144243
Festuca arundinacea	-------------1-11-2-----111
Holcus lanatus	-1-2212142232331334332333322
Lolium perenne	--------2112334446364557567
Phalaris aquatica	-------------3-1--1---1-111
Poa bulbosa	-1--------1--22----1-----11
Native phanerophytes	
Acacia dealbata	-111111---1-1--------------
Bursaria spinosa	---1-1----11--1------------
Coprosma quadrifida	--11-1111------------------
Exotic phanerophytes	
Ulex europaeus	1-1112-5--14214---1--1-11-1
Unassigned	
Native species	
Ranunculus spp.	-----1111-----1-1--1-111111
Galium spp.	1-11-1111111-111-------1-1-
Poa spp.	133-122--1-1--------1------
Dicotyledon spp.	21111111111111111-211-1-111
Monocotyledon spp.	11111-11--11---------------
Cyperaceae spp.	--1-11---111---1--1-1------
Unknown	
Poaceae spp.	111111111--21-1-1121111--11

Exotic species and life-form groups vary both in invasiveness and tolerance of improved pasture conditions. The most invasive life-form groups in areas with low exotic/total cover were therophytes and flat/versatile rosette hemicryptophyes. These groups also had the highest proportions of the species belonging to the life-form group that were invasive (Tables 2.6 and 2.8). Invasive flat/versatile rosette hemicryptophyes and therophytes were mainly adventitious species but also included *Trifolium subterraneum.* Caespitose and erect rosette hemicryptophtes were moderately invasive (Tables 2.6 and 2.8). An exotic phanerophyte, *Ulex europaeus*, was capable of invading pastures with low exotic cover.

All the exotic species were tolerant of improved pasture conditions apart from four species of therophytes that were found in native and semi-native pastures but not in improved pastures. These resembled native species in their distribution.

2.3.3 Sites grouped by management regimes, phosphorus level and broad habitat classes

Similarity of species composition within groups

The cross-validation table (Table 2.9), indicates that many of samples in groups 1 to 9 were reclassified back into their originally chosen groups. This indicates a high level of similarity within the groups chosen on the basis of phosphorus level and sowing regime for all but high levels of phosphorus in sown pastures. This indicates that the sowing regime, the phosphorus level and the geological substrate were important factors determining the vegetation of unsown and aerially sown pastures at all levels of phosphorus, and sown pastures at low levels of phosphorus. At moderate and high levels of phosphorus in sown pastures, the composition of the pastures would be more affected by the recent management.

Sixty-seven species, aggregated taxa and life-forms were tested. For 56 of these, significant GLMs were found which met the test for normality (Table 2.10). The results

of t-tests between groups are contained in Table 2.18, at the end of this chapter. The results in Table 2.18 are summarised in Tables 2.11 to 2.17

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Table 2.9. Cross-validation table derived from discriminant analysis. Groups are based on sowing regime, phosphorus level and habitat (Table 2.2), numbers represent the percentage of samples that the discriminant analysis reclassified into the originally chosen groups

		Percentage of samples reclassified into chosen groups and other groups																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Group	1	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	89	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0
	4	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5	0	0	0	0	80	0	0	0	0	0	0	10	0	10	0	0	0	0	0	0
	6	0	0	0	0	0	75	0	0	0	0	0	8	0	0	0	0	0	8	8	0
	7	0	0	0	0	0	0	85	0	0	0	0	8	8	0	0	0	0	0	0	0
	8	0	0	0	0	0	0	0	70	0	0	0	0	20	0	0	10	0	0	0	0
	9	0	0	0	0	0	0	0	0	79	0	0	0	16	0	0	0	0	5	0	0
	10	0	0	0	0	0	0	0	0	0	56	0	25	13	6	0	0	0	0	0	0
	11	0	0	0	0	0	0	0	0	0	0	75	6	19	0	0	0	0	0	0	0
	12	0	0	0	0	0	0	0	0	0	0	0	73	5	0	5	0	5	9	5	0
	13	0	0	0	0	0	0	0	0	0	2	5	2	81	0	2	0	0	8	2	0
	14	0	0	0	0	0	0	0	0	0	0	0	15	0	77	0	0	0	8	0	0
	15	0	0	0	0	0	0	0	0	0	0	0	15	23	0	54	0	0	8	0	0
	16	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	89	0	0	0	0
	17	0	0	0	0	0	0	0	8	0	0	0	8	0	0	15	0	69	0	0	0
	18	0	0	0	0	0	0	0	0	0	0	0	4	22	4	0	0	4	67	0	0
	19	0	0	0	0	0	0	0	7	0	0	0	0	7	0	7	0	0	7	73	0
	20	0	0	0	0	0	0	0	0	0	0	0	20	20	0	10	0	10	0	0	40

Table 2.10. List of species in order of life-forms and frequency of occurrence. Mean cover, the transformation used for the GLM and least squares means and the significance of the GLM are listed. N is the number of samples in which the species is found. None indicates no transformation, log indicates a $\log_{10}$ transformation and sqrt indicates a square root transformation

	N	% of total	Mean abun	Transform -ation	Signif of GLM
THEROPHYTES				none	P<0.001
Native					
Crassula sieberiana	33	9.32	0.0358	log	P<0.01
Exotic					
Aira caryophyllea	135	38.14	0.5163	sqrt	P<0.0001
Aphanes arvensis	147	41.53	0.2382	log	P<0.05
Arctotheca calendula	52	14.69	0.9364	log	ns
Briza minor	69	19.49	0.1088	log	P<0.0001
Bromus spp.	267	75.42	2.3967	log	P<0.0001
Capsella bursa-pastoris	43	12.15	0.0632	log	P<0.0001
Carduus spp.	104	29.38	0.9803	none	P<0.05
Cerastium spp.	252	71.19	0.5889	log	P<0.1
Cirsium vulgare	220	62.15	0.602	log	ns
Cynosurus echinatus	101	28.53	0.6483	log	P<0.1
Erodium cicutarium	111	31.36	0.2614	log	ns
Erodium moschatum	86	24.29	0.235	log	P<0.0001
Hordeum marinum	39	11.02	0.5915	log	P<0.001
Hordeum murinum	134	37.85	1.5368	sqrt	P<0.0001
Moenchia erecta	105	29.66	0.1569	log	P<0.0001
Montia fontana	64	18.08	0.1301	log	P<0.0001
Myosotis discolor	61	17.23	0.0544	log	P<0.0001
Poa annua	129	36.44	0.4038	log	P<0.0001
Trifolium spp.	328	92.66	10.182	log	P<0.0001
Trifolium subterraneum	304	85.88	24.956	log	P<0.0001
Vulpia spp.	297	83.9	7.1484	none	P<0.0001
CHAMAEPHYTES				log	P<0.001
Native					
Acaena novae-zelandiae	32	9.04	0.1054	log	P<0.001
GEOPHYTES					
Native					
Drosera peltata	32	9.04	0.0975	log	P<0.0001
HEMICRYPTOPHYTES FLAT/VERSATILE ROSETTE				log	P<0.001
Native					
Ehrharta stipoides	83	23.45	1.3951	sqrt	P<0.0001
Gnaphalium spp.	59	16.67	0.1027	sqrt	P<0.0001
Oxalis perennans	125	35.31	0.2942	log	P<0.0001
Solenogyne dominii	50	14.12	0.06	log	P<0.0001
Solenogyne gunnii	53	14.97	0.1819	log	P<0.0001

Table continued next page

Table 2.8. Continued from previous page

Exotic hemicryptophytes flat/versatile rosette					
Hypochoeris radicata	287	81.07	2.5409	log	P<0.0001
Leontodon taraxacoides	249	70.34	2.411	log	P<0.0001
Plantago coronopus	110	31.07	0.7266	log	ns
Plantago lanceolata	105	29.66	0.7895	none	P<0.05
Taraxacum officinale	88	24.86	0.0758	log	ns
Trifolium repens	198	55.93	4.9162	log	P<0.0001
HEMICRYPTOPHYTES ERECT ROSETTE				none	p<0.001
Native					
Acaena echinata	52	14.69	0.066	none	P<0.0001
Carex spp.	76	21.47	0.1216	log	P<0.0001
Juncus spp.	119	33.62	0.4666	log	P<0.1
Plantago varia	37	10.45	0.0524	log	P<0.0001
Exotic					
Agrostis capillaris	104	29.38	3.8099	log	P<0.0001
Poa pratensis	99	27.97	0.3923	log	P<0.05
HEMICRYPTOPHYTES PARTIAL ROSETTE				none	P<0.1
Native					
Leptorhynchos squamatus	37	10.45	0.1469	log	P<0.0001
Exotic					
Acetosella vulgaris	207	58.47	0.7477	sqrt	P<0.05
PROTO-HEMICRYPTOPHYTES				sqrt	P<0.001
Native					
Convolvulus erubescens	34	9.6	0.0424	log	P<0.0001
Dichondra repens	48	13.56	0.1918	log	P<0.0001
Geranium spp.	84	23.73	0.1183	none	P<0.0001
CAESPITOSE HEMICRYPTOPHYTES				sqrt	P<0.01
Native					
Danthonia spp.	158	44.63	5.3227	log	P<0.0001
Elymus scaber	35	9.89	0.281	log	P<0.1
Lomandra longifolia	50	14.12	0.7555	log	P<0.0001
Poa labillardierei	64	18.08	1.1946	log	P<0.0001
Poa rodwayi	63	17.8	0.6932	log	P<0.0001
Schoenus spp.	90	25.42	2.1157	log	P<0.0001
Stipa spp.	42	11.86	0.1906	log	P<0.0001
Themeda triandra	64	18.08	1.0552	log	P<0.0001
Exotic					
Anthoxanthum odoratum	40	11.3	0.4519	log	P<0.1
Dactylis glomerata	132	37.29	3.0209	log	P<0.0001
Holcus lanatus	159	44.92	2.2158	none	P<0.05
Lolium perenne	282	79.66	13.856	log	P<0.0001
Phalaris aquatica	32	9.04	0.4514	log	P<0.1
PHANEROPHYTES				log	P<0.001
Unassigned					
Galium spp.	32	9.04	0.0368	log	P<0.0001

Abundance of taxa and life-form groups related to levels of phosphorus

In unsown pastures there were differences in the abundance of native and exotic species which were related to levels of phosphorus. The taxa that were more abundant with higher phosphorus levels were all introduced (Table 2.11). The therophyte life-form, which was mainly composed of exotic species, was also less abundant with higher levels of phosphorus. The exotic species which were more abundant with higher phosphorus included sown pasture species, *Lolium perenne* and *Trifolium subterraneum,* and adventitious *Trifolium* spp. All but two of the exotic species which were more abundance were therophytes (Table 2.11).

The taxa that were less abundant with higher phosphorus were native, except for *Briza minor*. The majority of taxa for which no significant differences were found were exotic and were not present in sufficient quantities, in unsown pastures, for a difference to be determined. The abundance of 10 native taxa did not change with increasing phosphorus (Table 2.11). The life-form groups which were less abundant were the predominantly native chamaephytes, proto-hemicryptophytes (Table 2.11).

Even though the numbers of aerially sown pastures were relatively small, a large number of native taxa were less abundant at higher levels of phosphorus (Table 2.12). Increasing phosphorus corresponded with higher levels of annual *Bromus* spp., *Trifolium subterraneum* and *Lolium perenne* (Table 2.12). A larger number of native species were less abundant with higher phosphorus levels in aerially sown pastures than were less with higher phosphorus in unsown pastures. This suggests that phosphorus levels in aerially sown pastures were having a larger effect on native species.

Most native taxa were less abundant with increasing phosphorus in aerially sown pastures. The common native taxa that were not significantly less abundant with increasing phosphorus under any sowing regime were *Poa labillardierei, Ehrharta stipoides, Elymus scaber* and *Acaena novae-zelandiae.*

The taxa which were more abundant with higher levels of phosphorus in sown pastures were all exotic, however, there were a large number of exotic taxa which were less abundant with higher levels of phosphorus (Table 2.13).

Abundance of taxa and life-form groups related to sowing regimes

Aerial sowing resulted in a loss of some native taxa, and a corresponding rise in other native taxa, and exotic annuals. Aerial sowing was associated with lower cover of significant structural native species, *Themeda triandra* and *Lomandra longifolia.* However, the amounts of *Poa labillardierei* was not significantly different in aerially sown pastures compared to unsown pastures (Table 2.14).

Danthonia spp. was less abundant with higher levels of phosphorus regardless of sowing regime (Tables 2.11–2.13), but was more abundant in aerially sown pastures compared to unsown pastures.

Danthonia spp. was one of the few native taxa to be significantly more abundant following aerial sowing. There were a small number of pastures which had been sown, most more than 10 years previously, but some more recently, which had significant cover of *Danthonia* spp. (Fig. 2.10). In addition, some native pastures which had almost no exotic species had furrows indicating past ploughing, and native taxa had re-invaded the pastures.

Nine exotic taxa and the therophyte life-form group were found to be more abundant in sown compared to aerially sown pastures on igneous substrates (Table 2.15). They included the sown pasture species *Lolium perenne, Trifolium subterraneum* and *T. repens*. However, other species that are commonly sown, *Dactylis glomerata* and *Phalaris aquatica,* were not found to be more abundant in cultivated pastures (Table 2.15). Twenty native and 4 exotic species were less abundant in sown pastures compared to aerially sown pastures (Table 2.15).

The exotic taxa which were more abundant in sown pastures compared to unsown pastures were mostly therophytes and included *Trifolium subterraneum*, the seed of which was often aerially sown together with fertiliser, and adventitious *Trifolium* spp. (Table 2.16).

Cultivation appeared to have more effects on species on igneous substrates than on sedimentary substrates (Table 2.17). However, the comparison for sedimentary substrates was only able to be made for low levels of phosphorus and the numbers of samples were less than igneous substrates.

Most native taxa were less abundant in sown compared to unsown pastures, including the most common and abundant ones. Six exotic taxa were also less abundant in the sown pastures. These taxa, such as *Trifolium* spp., were abundant in aerially sown pastures and comparatively less abundant in cultivated pastures. However, a large number of exotic species and a small number of native taxa did not appear to differ in abundance between aerially sown and cultivated pastures (Table 2.17).

Abundance of taxa and life-form groups related to geological substrates

Some native taxa on unsown pastures were more abundant on one or the other geological substrates Six native taxa were more abundant on igneous than sedimentary substrates on unsown pastures. They included *Themeda triandra, Poa rodwayi* and *Schoenus* spp. *Poa labillardierei* and chamaephytes were more abundant on sedimentary the igneous substrates (Table 2.16).

Abundance of taxa and life-form groups related to rainfall on sown pastures

Erect rosette and flat/versatile rosette hemicryptophytes and were more abundant on sown pastures with higher rainfall on both igneous and sedimentary substrates (Table 2.17). Of the 11 exotic species which were more abundant 8 were perennial and 3 annual. Therophytes were less abundant on pastures with higher rainfall on both substrates (Table 2.17). Exotic species which were more abundant in pastures with higher rainfall included *Trifolium repens* and *Holcus lanatus*, while *Trifolium subterraneum*, therophytes, *Vulpia* spp., *Bromus* spp. and *Dactylis glomerata* were more abundant in lower rainfall areas (Table 2.17). For the majority of native taxa there appeared to be no difference with rainfall. However, many of these were recorded as having no difference because they were uncommon in sown pastures.

Table 2.11. Table of species, genera and life-forms which were more abundant or less abundant with increasing phosphorus in unsown pastures. * indicates introduced taxa

More abundant with increasing phosphorus in unsown pastures	**Less abundant with increasing phosphorus in unsown pastures**
Therophytes	Caespitose hemis
**Bromus* spp.	Chamaephytes
**Carduus* spp.	Erect rosette hemis
**Cirsium vulgare*	Proto-hemis
**Lolium perenne*	**Briza minor*
**Myostis discolor*	*Convolvulus erubescens*
Poa labillarierei	*Danthonia* spp.
**Poa pratensis*	*Dichondra repens*
**Trifolium repens*	*Drosera peltata*
**Trifolium* spp.	*Galium* spp.
**Trifolium subterraneum*	*Geranium solanderi*
**Vulpia* spp.	*Leptorynchos squamatus*
	Poa rodwayi
	Schoenus spp.
	Solenogyne dominii
	Stipa spp.
	Themeda triandra

Table 2.12. Table of species, genera and life-forms which were more abundant or less abundant with increasing phosphorus in aerially sown pastures. * indicates introduced taxa

More abundant with increasing phosphorus in aerially sown pastures	**Less abundant with increasing phosphorus in aerially sown pastures**
Therophytes	Erect rosette hemis
**Bromus* spp.	Proto-hemis
**Lolium perenne*	*Acaena echinata*
**Trifolium subterraneum*	**Briza minor*
	Carex spp.
	Convolvulus erubescens
	Crassula sieberiana
	Danthonia spp.
	Dichondra repens
	Galium spp.
	Geranium solanderi
	Gnaphalium spp.
	Leptorynchos squamatus
	Lomandra longifolia
	**Moenchia erecta*
	Oxalis perennans
	Plantago varia
	Poa rodwayi
	Solenogyne gunnii
	Stipa spp.
	Themeda triandra

Table 2.13. Table of species, genera and life-forms which were more abundant or less abundant with increasing phosphorus in sown pastures. * indicates introduced taxa

More abundant with increasing phosphorus in sown pastures	**Less abundant with increasing phosphorus in sown pastures**
Therophytes	Chamaephytes
Partial rosette hemis	Flat/versatile rosette hemis
Caespitose hemis	Erect rosette hemis
**Bromus* spp.	*Acaena novae-zelandii*
**Capsella bursa-pastoris*	**Agrostis capillaris*
**Carduus* spp.	**Aira caryophyllea*
**Cirsium vulgare*	**Anthoxanthum odoratum*
**Erodium cicutarium*	**Aphanes arvensis*
**Erodium moschatum*	*Danthonia* spp.
**Hordeum murinum*	*Drosera peltata*
**Lolium perenne*	**Holcus lanatus*
**Myostis discolor*	**Hypochoeris radicata*
**Taraxacum officinale*	**Juncus* spp.
**Trifolium* spp.	**Leontodon taraxacoides*
	**Moenchia erecta*
	Oxalis perennans
	**Phalaris aquatica*
	Schoenus spp.
	Solenogyne dominii

Table 2.14. Table of species, genera and life-forms which were more abundant or less abundant in aerially sown pastures compared to unsown pastures. * indicates introduced taxa.

More abundant in aerially sown pastures than unsown pastures	**Less abundant in aerially sown pastures than unsown pastures**
Therophytes	Chamaephytes
Acaena echinata	**Carduus* spp.
Carex spp.	*Drosera peltata*
**Cerastium* spp.	*Ehrharta stipoides*
**Cynosurus echinatus*	*Gnaphalium* spp.
Danthonia spp.	*Lomandra longifolia*
Galium spp.	*Plantago varia*
**Lolium perenne*	*Schoenus* spp.
**Myosotis discolor*	*Solenogyne gunnii*
**Plantago lanceolata*	*Themeda triandra*
Solenogyne dominii	
Stipa spp.	
**Trifolium* spp.	
**Trifolium subterraneum*	

Table 2.15. Table of species, genera and life-forms which were more abundant or less abundant in sown pastures compared to aerially sown pastures. * indicates introduced taxa

More abundant in sown pastures than aerially sown pastures	**Less abundant in sown pastures than aerially sown pastures**
Therophytes	Chamaephytes
**Agrostis capillaris*	Proto-hemis
**Anthoxanthum odoratum*	Phanerophytes
**Holcus lanatus*	*Acaena echinata*
**Lolium perenne*	**Aira caryophyllea*
**Montia fontana*	**Briza minor*
**Trifolium repens*	**Capsella bursa-pastoris*
**Trifolium* spp.	**Carduus* spp.
**Trifolium subterraneum*	*Carex* spp.
**Vulpia* spp.	*Convolvulus erubescens*
	Danthonia spp.
	Dichondra repens
	Ehrharta stipoides
	Elymus scaber
	Galium spp.
	Geranium spp.
	Gnaphalium spp.
	Leptorynchos squamatus
	Lomandra longifolia
	Oxalis perennans
	Plantago varia
	Poa labillardierei
	Poa rodwayi
	Schoenus spp.
	Solenogyne gunnii
	Stipa spp.
	Themeda triandra

Table 2.16. List of species, genera and life-forms which were more abundant or less abundant on igneous and sedimentary substrates in high rainfall sites on sown and unsown pastures. No species or life-form groups were less abundant on igneous compared to sedimentary sown pastures. * indicates introduced taxa

Unsown pastures **More abundant on igneous substrates than on sedimentary substrates**	**Less abundant on igneous substrates than on sedimentary substrates**	**Sown pastures** **More abundant on igneous substrates than on sedimentary substrates**
Erect rosette hemis	Chamaephytes	Erect rosette hemis
**Briza minor*	*Acaena novae-zelandiae*	Partial rosette hemis
Convolvulus erubescens	**Capsella bursa-pastoris*	Chamaephytes
Drosera peltata	*Elymus scaber*	*Acaena novae-zelandiae*
Leptorynchos squamatus	*Oxalis perennans*	**Capsella bursa-pastoris*
Plantago varia	*Poa labillardierei*	*Drosera peltata*
Poa rodwayi	*Solenogyne gunnii*	*Elymus scaber*
Schoenus spp.		**Hypochoeris radicata*
Solenogyne dominii		**Moenchia erecta*
Themeda triandra		**Plantago lanceolata*
		**Acetosella vulgaris*
		Solenogyne dominii
		Solenogyne gunnii
		**Trifolium* spp.

Table 2.17. List of species, genera and life-forms which were more abundant or less abundant with increasing rainfall. The comparisons are made for sown pastures only. * indicates introduced taxa

IGNEOUS SUBSTRATES

More abundant with increasing rainfall on sown pastures	**Less abundant with increasing rainfall on sown pastures**
Erect rosette hemis	Therophytes
Flat/vers rosette hemis	*Acaena echinata*
**Agrostis capillaris*	**Bromus* spp.
**Anthoxanthum odoratum*	**Dactylis glomerata*
**Aphanes arvensis*	**Erodium moschatum*
Drosera peltata	**Phalaris aquatica*
**Holcus lanatus*	**Trifolium subterraneum*
**Montia fontana*	
**Plantago lanceolata*	
**Poa annua*	
Solenogyne dominii	
**Taraxacum officinale*	
**Trifolium repens*	

SEDIMENTARY SUBSTRATES

More abundant with increasing rainfall	**Less abundant with increasing rainfall**
Erect rosette hemis	Therophytes
Flat/vers rosette hemis	**Aira caryophyllea*
**Agrostis capillaris*	**Bromus* spp.
**Anthoxanthum odoratum*	*Crassula sieberana*
**Aphanes arvensis*	**Dactylis glomerata*
**Holcus lanatus*	**Erodium moschatum*
**Hypochoeris radicata*	**Hordeum marinum*
**Leontodon taraxacoides*	**Montia fontana*
**Moenchia erecta*	**Vulpia* spp.
**Poa annua*	
**Trifolium repens*	

2.4 Discussion

2.4.1 Condition of native and semi-native pastures

The sites consisted of a wide range of pasture types from the most 'ideal' improved pastures dominated by sown species, through to improved pastures that had lost their sown species and were dominated by annual grasses, regarded by most landholders as weeds. Some sown pastures were dominated by *Danthonia* spp., and appeared to have reverted or been re-invaded. Other pastures contained approximately equal cover of native and exotic species and some were dominated by native species with a very small cover of exotic species.

Much of the native run country had a higher species richness than most of the figures given for Victoria and NSW (Tremont and McIntyre 1994). Almost all sites had some exotic species, as noted by Fensham (1989). The fact that native species richness was high within the 15 m^2 quadrats (where exotic species richness reached 10 and approximately 14% of total cover), suggests that a low level of exotic invasion in native pastures was not associated with a major decrease of the native flora of the pastures.

The relatively low abundance of *Themeda triandra* in unsown pastures on igneous substrates (mean cover 7.6%), compared to *Danthonia* spp. (16.2%) and *Schoenus* spp. (12.5%), suggests that *Themeda triandra* was reduced by grazing management. The cover of *Themeda triandra* in undisturbed native grassland is usually much higher (Chapter 3). The low cover indicates that *Themeda triandra* could not have had a role as a dominant structural species and that the structure of the pastures had been altered by grazing management.

There would almost certainly have been a small component of native species that would have been lost in the early years of settlement and grazing. There are a number of native species which were sensitive to grazing, and had particular disturbance requirements, such as small-scale soil disturbance to create microsites for germination (Gilfedder and Kirkpatrick 1994). The loss of these species can be partly attributed to grazing,

although loss of native fauna and the suppression of fire in the landscape may also be factors.

The importance of city parks and cemeteries as refuges for rare and threatened species (Kirkpatrick *et al.* 1988) also indicates the complete elimination by grazing of a small but important component of the native vegetation. However, it appears that although there is likely to a have been a loss of some grazing-sensitive native species and an alteration of structure associated with a loss of a shrub layer and tree regeneration, many native pastures are relatively intact.

While the condition of run country appears to be relatively stable, a misleading appearance of stability may be due to changes occurring at a slow rate. Monitoring has not taken place and few records of past conditions are available. There may be long term and gradual changes occurring caused by long-term grazing. Long-term changes could include loss or alteration of the mid-storey and decline of some *Eucalyptus* spp. Such changes are likely to be associated with changes in pasture composition.

Some native pastures may have been grazed for more than a century. A low to moderate level of grazing of the run country may be sustainable without the further loss of native species richness or structure. However, this is not certain. Extreme weather events are thought to cause vegetation changes that can persist in the long term (Austin and Williams 1988). Tree decline in bush runs affects 40% of the Midlands and affect up to 80% of trees in the worst affected areas. Grazing prevents tree establishment in many areas and may be an important factor in the decline. The loss of the dominant *Eucalyptus* spp. and shrub layer probably would affect the native grassy vegetation.

2.4.2 Effects of the levels of phosphorus and sowing regimes

There are substantial vegetation changes associated with higher levels of phosphorus in unsown pastures. These higher levels of phosphorus in unsown pastures may be naturally occurring. In this case, the pastures with naturally higher levels of phosphorus may be predisposed to invasion by exotic species.

The levels of nutrients may be increased in conjunction with agricultural management. It is possible that higher levels of phosphorus, found in some of the unsown pastures, may be a result of unreported fertiliser addition. Otherwise grazing can concentrate nutrients in the upper soil layers and stock can deposit nutrients from improved pasture areas in their faeces.

The higher phosphorus levels and associated higher levels of sown and adventitious clovers would result in higher plant growth and a higher carrying capacity, resulting in a higher rate of defoliation. The decline of native species may be due to a lower tolerance of defoliation than the exotic species.

The apparent decline of native species at higher levels of phosphorus may be due to the exotic pasture being favoured by the higher nutrient levels (e.g. Hobbs and Atkins 1988, Hobbs 1989). Exotic species may be more able than native species to respond to higher nutrient levels and thus would be able to compensate for an increase in stocking pressure with more growth.

The exotic species which are associated with higher levels of phosphorus in unsown pastures include species that are often sown as seed with application of fertiliser, such as *Trifolium subterraneum* and *Lolium perenne*. The higher levels of adventitious legumes appear to be responding to the phosphorus levels and would be adding nitrogen to the system by N-fixation. Therophytes in general and annual grasses, *Bromus* spp. and *Vulpia* spp. and the thistles, *Carduus* spp. and *Cirsium vulgare,* were also more abundant in unsown pastures with higher phosphorus and appear to be responding to the higher levels of phosphorus.

The abundance of *Danthonia* spp. in aerially sown pastures, which is higher than in unsown pastures with both lower and higher levels of phosphorus, suggests that *Danthonia* spp. is promoted by aerial sowing. The original native vegetation would have been disturbed by the nutrient and exotic seed addition, however, with time the exotic species would decline. Following which *Danthonia* spp. may have increased to higher than its original abundance. *Danthonia* spp. were also common in improved pastures in the Goulburn region of NSW (Robinson et al. 1993).

Many of the species that increase following aerial sowing, such as *Danthonia* spp. and adventitious clovers (*Trifolium* spp.), are desirable for stock grazing. It may be that an increase in undesirable species and a decrease in pasture condition would occur over the long-term. Long-term monitoring could determine whether this form of management of native pastures is sustainable.

Higher levels of phosphorus and aerial sowing, and sowing and cultivation, appear to have additive negative effects on native species richness and native species cover. Many native species were not present in sown pastures in sufficient quantities for statistical comparisons to be made.

When the original native vegetation is disturbed by aerial sowing and/or cultivation and introduced pasture species do not form a long-term pasture, *Danthonia* spp. can become abundant.

This appears to be common with drier sites that are marginal for pasture improvement. It may also be due to pasture improvement being undertaken in a poor year. *Danthonia* spp. may persist in low quantities but re-establish at higher levels than commonly found in undisturbed vegetation.

Native species, such as *Poa labillardierei* and *Juncus* spp., were abundant in some semi-native pastures. Tremont and McIntyre (1994) have considered that the similar species, *Poa sieberana,* probably had not declined with agricultural management in pastures of the Northern Tablelands of NSW. In Tasmania, these species may decline with long-term grazing but may increase under some management regimes. *Poa labillardierei* and *Juncus* spp. are tough erect plants that are relatively unpalatable as they become older and larger. More palatable species between them may be preferentially grazed. They often form a mid-storey or a matrix of tall tussocks, and may be improving the microclimates between them by reducing ground surface wind speed, evaporation and insolation. They also provide shelter for stock and can provide feed at critical times such as over winter.

The cultivation, fertilisation and sowing of native pasture cause the almost complete replacement of native species. In older sown pastures the sown species component can decrease rapidly (Thompson 1995). These pastures would tend to be the ones with less

favourable conditions for sown species, or for which the high costs of reseeding or maintenance cannot be justified by the landholders.

2.4.3 Responses of the life-form groups

The classification of species into life-forms and the analysis of trends with the life-form in this thesis appears to provide a useful tool to understanding the trends as reported in McIntyre *et al.* (1995). However, it does not alone account for the vegetation response. Other important factors which would be likely to improve this classification include origin of the species, stature and palatability.

There were difficulties in assigning life-form classes to particular species. The morphologies of species such as *Juncus* spp., *Lomandra longifolia* and *Lepidosperma laterale* and some grasses were in some ways intermediate between the caespitose and erect hemicryptophyte classes but were still able to be placed into life-form groups. Any classification scheme based on species is likely to have problems with categorisation of species.

A consistent feature of the responses of species within life-form groups was variation in responses to the agricultural management. The chamaephyte life-form was less abundant with a low level of exotic species invasion, which is correlated with grazing and disturbance. Chamaephytes generally have buds exposed to browsing, although some have sharp spines or leaves which deter browsing. Most chamaephytes conform to the life-form trend. However, the often prostrate *Acaena novae-zelandiae* is more abundant with sowing and is one of the most persistent native species in improved pastures.

The decrease in chamaephytes, phanerophytes, geophytes and erect hemicryptophytes and increase in therophytes and low stature species with increasing grazing pressure was also noted in the NSW Northern Tablelands (McIntyre *et al.* 1995).

The other native species to decrease at low levels of invasion are therophytes, partial rosette hemicryptophytes and proto-hemicryptophytes. The most common native

therophyte, the small statured *Crassula sieberiana*, is an exception to the life-form trend and has its highest abundance in aerially sown pastures with low phosphorus.

Hemicryptophytes which can resprout following defoliation from ground level buds can be resistant to grazing. The native hemicryptophytes that are tolerant of grazing in native and semi-native pastures include flat/versatile rosette hemicryptophytes which avoid grazing by low growth form. Erect rosette hemicryptophytes which have tough leaves are relatively tolerant as are caespitose hemicryptophytes, where the tussock form many give protection to meristems.

The life-forms of native species that are found with the different pasture types and management regimes are not the same as the life-forms of the exotic species found under the same conditions. Exotic therophytes and flat/versatile rosette hemicryptophytes are the most invasive life-forms in native pastures. Exotic therophytes are a broad group and include *Trifolium subterraneum,* a sown species, and a host of adventitious grasses and forbs with varying degrees of invasiveness and tolerance to pasture management practices.

Exotic therophytes can avoid grazing pressure by growing within the short time when there is an abundance of feed (Wilson 1990). The aspects of reproduction that confer 'weediness' (Baker 1965), such as high seed production, germination under a wide range of conditions, rapid growth, and morphological plasticity are also important. The invasiveness of flat/versatile rosette hemicryptophytes can also be explained by the above aspects of weediness.

In conclusion, there appeared to be trends in the life-form groups, however, the variation in the responses was large and the classification would be improved by considering also the origin, the palatability and stature of the species.

Table 2.18. Species with numbers of samples in which the species is found. Means of cover values for samples with combinations of sowing regime, phosphorus level and habitat are shown. Listed below are probability values of pairs of samples being the same

Numbers of samples in groups

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 n=42		2 n=9	
unsown med P		3 n=9			
unsown high P					
aerial low P		4 n=14			
aerial med P		5 n=10			
aerial high P					
sown low P	6 n=12	7 n=13	8 n=10	9 n=19	
sown med P	10 n=16	11 n=16	12 n=22	13 n=62	14 n=13
sown high P	15 n=13	16 n=9	17 n=13	18 n=27	19 n=15

ungrouped n= 10

THEROPHYTES
Untransformed data used
Significance of GLM P<0.001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 12.40		2 20.27	
unsown med P		3 52.47			
unsown high P					
aerial low P		4 31.33			
aerial med P		5 63.43			
aerial high P					
sown low P	6 55.57	7 57.42	8 68.75	9 44.51	
sown med P	10 84.86	11 45.15	12 73.44	13 55.23	14 69.99
sown high P	15 64.04	16 55.97	17 82.56	18 65.40	19 63.61

ungrouped 63.90

1-2: ns	1-3: 0.0030	1-4: 0.0390	1-7: 0.0001	2-9: 0.0438
3-5: ns	3-11: ns	4-5: 0.0092	4-7: 0.0227	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: 0.0368	6-14: ns
6-10: 0.0100	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: 0.0020
10-12: ns	11-13: ns	12-13: 0.0137	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Native *Crassula sieberana* n=33
Log transformed data used
Significance of GLM P<0.01

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.095		2 0.055	
unsown med P		3 0.056			
unsown high P					
aerial low P		4 0.166			
aerial med P		5 0.00			
aerial high P					
sown low P	6 0.083	7 0.038	8 0.00	9 0.008	
sown med P	10 0.00	11 0.010	12 0.106	13 0.002	14 0.051
sown high P	15 0.00	16 0.00	17 0.025	18 0.00	19 0.00

ungrouped 0.00

1-2: ns	1-3: ns	1-4: ns	1-7: ns	2-9: ns
3-5: ns	3-11: ns	4-5: 0.0014	4-7: 0.0093	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: 0.0278	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Exotic *Aira caryophylla* n=135
Square root transformed data used
Significance of GLM P<0.0001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 1.44		2 1.81	
unsown med P unsown high P		3 1.07			
aerial low P		4 1.10			
aerial med P		5 0.67			
aerial high P					
sown low P	6 1.07	7 0.53	8 1.62	9 0.16	
sown med P	10 0.13	11 0.38	12 0.03	13 0.39	14 0.09
sown high P	15 0.00	16 0.00	17 0.00	18 0.02	19 0.02

ungrouped 0.05

1-2: ns	1-3: ns	1-4: ns	1-7: 0.0405	2-9: 0.0023
3-5: ns	3-11: ns	4-5: ns	4-7: ns	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: 0.0180	6-14: ns
6-10: ns	7-11: ns	8-12: 0.0045	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Aphanes arvensis n=147
Log transformed data used
Significance of GLM P<0.05

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown lowP		1 0.26		2 0.08	
unsown medP unsown highP		3 0.33			
aerial lowP		4 0.29			
aerial medP		5 0.25			
aerial highP					
sown lowP	6 0.14	7 0.27	8 0.07	9 0.17	14 0.00
sown medP	10 0.18	11 0.79	12 0.13	13 0.41	
sown highP	15 0.09	16 0.22	17 0.10	18 0.07	19 0.03

ungrouped 0.35

1-2: ns	1-3: ns	1-4: ns	1-7: ns	2-9: ns
3-5: ns	3-11: ns	4-5: ns	4-7: ns	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: 0.0106	14-19: ns	10-11: 0.0284
10-12: ns	11-13: ns	12-13: 0.0365	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Arctotheca calendula n=52
Log transformed data used
GLM not significant

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.03		2 0.70	
unsown med P		3 0.00			
unsown high P					
aerial low P		4 1.12			
aerial med P		5 0.00			
aerial high P					
sown low P	6 1.10	7 2.92	8 1.31	9 0.76	
sown med P	10 0.44	11 1.92	12 1.63	13 0.75	14 0.93
sown high P	15 0.64	16 0.00	17 0.33	18 1.99	19 1.03

ungrouped 1.55

1-2: ns	1-3: ns	1-4: ns	1-7: ns	2-9: ns
3-5: ns	3-11: ns	4-5: ns	4-7: ns	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Briza minor n=69
Log transformed data used
Significance of GLM P<0.0001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.37		2 0.17	
unsown med P		3 0.04			
unsown high P					
aerial low P		4 0.44			
aerial med P		5 0.17			
aerial high P					
sown low P	6 0.03	7 0.06	8 0.05	9 0.06	
sown med P	10 0.00	11 0.04	12 0.01	13 0.13	14 0.10
sown high P	15 0.00	16 0.00	17 0.00	18 0.00	19 0.01

ungrouped 0.00

1-2: 0.0223	1-3: 0.0003	1-4: ns	1-7: 0.0002	2-9: ns
3-5: ns	3-11: ns	4-5: 0.0316	4-7: 0.0005	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Bromus spp. n=267
Log transformed data used
Significance of GLM P<0.0001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.17		2 0.76	
unsown med P		3 2.93			
unsown high P					
aerial low P		4 0.85			
aerial med P		5 5.58			
aerial high P					
sown low P	6 1.98	7 1.79	8 1.23	9 1.69	
sown med P	10 4.25	11 0.86	12 4.55	13 1.91	14 5.10
sown high P	15 2.69	16 2.94	17 3.27	18 3.84	19 3.98

ungrouped 1.534

1-2: ns	1-3: 0.0181	1-4: ns	1-7: ns	2-9: ns
3-5: ns	3-11: ns	4-5: 0.0080	4-7: ns	5-11: 0.0071
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: 0.0428
6-10: ns	7-11: ns	8-12: 0.0374	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: 0.0076
10-12: ns	11-13: ns	12-13: 0.0079	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Capsella bursa-pastoris n=43
Log transformed data used
Significance of GLM P<0.001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.01		2 0.33	
unsown med P		3 0.09			
unsown high P					
aerial low P		4 0.00			
aerial med P		5 0.05			
aerial high P					
sown low P	6 0.00	7 0.01	8 0.00	9 0.00	
sown med P	10 0.04	11 0.02	12 0.07	13 0.02	14 0.03
sown high P	15 0.05	16 0.09	17 0.67	18 0.03	19 0.03

ungrouped 0.22

1-2: 0.0108	1-3: ns	1-4: ns	1-7: ns	2-9: 0.0150
3-5: ns	3-11: ns	4-5: ns	4-7: ns	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: 0.0010	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: 0.0010	17-18: 0.0010	16-18: ns	17-19: 0.0010	

Carduus spp. n=104
Untransformed data used
Significance of GLM P<0.1

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.08		2 0.11	
unsown med P		3 4.72			
unsown high P					
aerial low P		4 0.70			
aerial med P		5 0.48			
aerial high P					
sown low P	6 0.03	7 0.12	8 0.12	9 0.65	
sown med P	10 1.23	11 0.93	12 0.23	13 0.74	14 0.88
sown high P	15 1.11	16 3.31	17 3.79	18 1.18	19 1.65

ungrouped 2.30

1-2: ns	1-3: 0.0006	1-4: ns	1-7: ns	2-9: ns
3-5: 0.0116	3-11: 0.0127	4-5: ns	4-7: ns	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: 0.0054	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: 0.0339	16-18: ns	17-19: ns	

Cerastium spp. n=252
Log transformed data used
Significance of GLM P<0.1

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.31		2 0.37	
unsown med P		3 0.30			
unsown high P					
aerial low P		4 0.82			
aerial med P		5 0.25			
aerial high P					
sown low P	6 0.40	7 0.37	8 0.20	9 0.36	
sown med P	10 0.41	11 0.51	12 0.88	13 0.74	14 0.90
sown high P	15 0.28	16 0.46	17 0.46	18 0.82	19 0.78

ungrouped 1.73

1-2: ns	1-3: ns	1-4: 0.0032	1-7: ns	2-9: ns
3-5: ns	3-11: ns	4-5: ns	4-7: ns	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Cirsium vulgare n=220
Log transformed data used
GLM not significant

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.31		2 0.33	
unsown med P		3 0.85			
unsown high P					
aerial low P		4 0.58			
aerial med P		5 0.70			
aerial high P					
sown low P	6 1.02	7 0.73	8 0.30	9 0.51	
sown med P	10 0.72	11 0.33	12 0.27	13 0.58	14 0.39
sown high P	15 1.24	16 1.57	17 0.94	18 0.32	19 1.20

ungrouped 0.76

1-2: ns	1-3: 0.0481	1-4: ns	1-7: ns	2-9: ns
3-5: ns	3-11: ns	4-5: ns	4-7: ns	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: 0.0372	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: 0.0147	17-19: ns	

Cynosurus echinatus n=101
Log transformed data used
Significance of GLM P=0.1

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.37		2 0.09	
unsown med P		3 0.19			
unsown high P					
aerial low P		4 0.82			
aerial med P		5 2.56			
aerial high P					
sown low P	6 0.88	7 1.08	8 0.15	9 1.37	
sown med P	10 1.32	11 0.06	12 0.99	13 0.35	14 0.06
sown high P	15 0.28	16 0.00	17 1.79	18 0.07	19 1.71

ungrouped 0.15

1-2: ns	1-3: ns	1-4: ns	1-7: ns	2-9: ns
3-5: 0.0183	3-11: ns	4-5: ns	4-7: ns	5-11: 0.0024
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: 0.0358
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Erodium cicutarium n=111
Log transformation data used
GLM not significant

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.04		2 0.04	
unsown med P		3 0.07			
unsown high P					
aerial low P		4 0.07			
aerial med P		5 0.10			
aerial high P					
sown low P	6 0.06	7 0.10	8 0.03	9 0.02	
sown med P	10 0.45	11 0.08	12 0.73	13 0.44	14 0.64
sown high P	15 0.60	16 0.02	17 0.33	18 0.15	19 0.51

ungrouped 0.12

1-2: ns	1-3: ns	1-4: ns	1-7: ns	2-9: ns
3-5: ns	3-11: ns	4-5: ns	4-7: ns	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: 0.0450	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Erodium moschatum n=86
Log transformed data used
Significance of GLM P<0.0001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.00		2 0.02	
unsown med P		3 0.02			
unsown high P					
aerial low P		4 0.00			
aerial med P		5 0.10			
aerial high P					
sown low P	6 0.00	7 0.04	8 0.55	9 0.03	
sown med P	10 0.76	11 0.01	12 0.70	13 0.15	14 0.13
sown high P	15 0.18	16 1.39	17 0.85	18 0.21	19 0.20

ungrouped 0.20

1-2: ns	1-3: ns	1-4: ns	1-7: ns	3-5: ns
2-9: ns	3-11: ns	4-5: ns	4-7: ns	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: 0.0018	7-11: ns	8-12: ns	9-13: ns	10-15: 0.0293
11-16: 0.0001	12-17: ns	13-18: ns	14-19: ns	10-11: 0.0010
10-12: ns	11-13: ns	12-13: 0.0047	12-14: 0.0442	15-16: 0.0013
15-17: 0.0332	17-18: 0.0301	16-18: 0.0008	17-19: 0.0299	

Hordeum marinum n=39
Log transformed data used
Significance of GLM P<0.001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown lowP		1 0.00		2 0.00	
unsown medP		3 0.04			
unsown highP					
aerial lowP		4 0.01			
aerial medP		5 1.58			
aerial highP					
sown lowP	6 0.61	7 0.00	8 0.57	9 0.02	14 4.55
sown medP	10 0.43	11 0.00	12 0.61	13 0.01	
sown highP	15 1.97	16 3.17	17 1.23	18 0.73	19 0.66

ungrouped 0.02

1-2: ns	1-3: ns	1-4: ns	1-7: ns	2-9: ns
3-5: ns	3-11: ns	4-5: ns	4-7: ns	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: 0.0001	10-15: ns
11-16: 0.0025	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: 0.0103	12-13: 0.0001	12-14: ns	15-16: 0.0429
15-17: ns	17-18: ns	16-18: 0.0208	17-19: ns	

Hordeum murinum n=134
Square root transformed data used
Significance of GLM P<0.0001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.00		2 0.05	
unsown med P		3 0.16			
unsown high P					
aerial low P		4 0.03			
aerial med P		5 1.23			
aerial high P					
sown low P	6 1.60	7 0.05	8 0.25	9 0.06	
sown med P	10 1.58	11 0.36	12 1.61	13 0.74	14 1.10
sown high P	15 10.15	16 0.72	17 8.54	18 0.88	19 3.40

ungrouped 5.41

1-2: ns	1-3: ns	1-4: ns	1-7: ns	2-9: ns
3-11: ns	3-5: ns	4-5: ns	4-7: ns	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: 0.0001
11-16: ns	12-17: 0.0001	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: 0.0001
15-17: ns	17-18: 0.0001	16-18: ns	17-19: 0.0028	

Moenchia erecta n=105
Log transformed data used
Significance of GLM P<0.0001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.22		2 0.13	
unsown med P		3 0.22			
unsown high P					
aerial low P		4 0.51			
aerial med P		5 0.17			
aerial high P					
sown low P	6 0.20	7 0.40	8 0.08	9 0.09	
sown med P	10 0.00	11 0.21	12 0.03	13 0.25	14 0.01
sown high P	15 0.01	16 0.04	17 0.01	18 0.01	19 0.02

ungrouped 0.30

1-2: ns	1-3: ns	1-4: 0.0024	1-7: ns	2-9: ns
3-11: ns	3-5: ns	4-5: 0.0076	4-7: ns	5-11: ns
6-7: ns	6-8: ns	7-9: 0.0073	8-9: ns	6-14: ns
6-10: 0.0469	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: 0.0346	14-19: ns	10-11: 0.0232
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Montia fontana n=64
Log transformed data used
Significance of GLM P<0.01

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.03		2 0.00	
unsown med P		3 0.00			
unsown high P					
aerial low P		4 0.00			
aerial med P		5 0.02			
aerial high P					
sown low P	6 0.00	7 0.33	8 0.03	9 0.85	
sown med P	10 0.00	11 0.05	12 0.00	13 0.29	14 0.03
sown high P	15 0.04	16 0.04	17 0.00	18 0.13	19 0.00

ungrouped 0.03

1-2: ns	1-3: ns	1-4: ns	1-7: 0.0103	2-9: ns
3-11: ns	3-5: ns	4-5: ns	4-7: 0.0162	5-11: ns
6-7: 0.0206	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: 0.0380	12-13: 0.0014	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Myostis discolor n=61
Log transformed data used
Significance of GLM P<0.0001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.11		2 0.11	
unsown med P		3 0.20			
unsown high P					
aerial low P		4 0.18			
aerial med P		5 0.25			
aerial high P					
sown low P	6 0.03	7 0.06	8 0.00	9 0.01	
sown med P	10 0.02	11 0.01	12 0.02	13 0.03	14 0.01
sown high P	15 0.00	16 0.11	17 0.00	18 0.01	19 0.03

ungrouped 0.07

1-2: ns	1-3: 0.0312	1-4: 0.0423	1-7: ns	2-9: ns
3-11: 0.0005	3-5: ns	4-5: ns	4-7: 0.0266	5-11: 0.0001
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: 0.0495
15-17: ns	17-18: ns	16-18: 0.0380	17-19: ns	

Poa annua n=129
Log transformed data used
Significance of GLM P<0.0001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.02		2 0.02	
unsown med P		3 0.02			
unsown high P					
aerial low P		4 0.07			
aerial med P		5 0.03			
aerial high P					
sown low P	6 0.04	7 0.15	8 0.03	9 0.18	
sown med P	10 0.02	11 0.40	12 0.18	13 0.64	14 0.26
sown high P	15 0.36	16 0.22	17 0.14	18 2.52	19 0.12

ungrouped 0.18

1-2: ns	1-3: ns	1-4: ns	1-7: ns	2-9: ns
3-11: ns	3-5: ns	4-5: ns	4-7: ns	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: 0.0191	10-15: ns
11-16: ns	12-17: ns	13-18: 0.0001	14-19: ns	10-11: 0.0446
10-12: ns	11-13: ns	12-13: 0.0154	12-14: ns	15-16: ns
15-17: ns	17-18: 0.0001	16-18: 0.0001	17-19: ns	

Trifolium spp. n=328
Log transformed data used
Significance of GLM P<0.0001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 5.13		2 3.13	
unsown med P		3 17.47			
unsown high P					
aerial low P		4 12.34			
aerial med P		5 23.08			
aerial high P					
sown low P	6 12.77	7 10.62	8 3.38	9 5.29	
sown med P	10 14.83	11 11.25	12 9.96	13 8.24	14 14.98
sown high P	15 10.86	16 14.37	17 13.11	18 11.06	19 8.82

ungrouped 16.00

1-2: ns	1-3: 0.0005	1-4: 0.0016	1-7: 0.0158	2-9: ns
3-11: ns	3-5: ns	4-5: ns	4-7: ns	5-11: 0.0485
6-7: ns	6-8: 0.0016	7-9: 0.0360	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: 0.0234	9-13: 0.0405	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Trifolium subterraneum n=304
Log transformed data used
Significance of GLM P<0.0001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 1.88		2 8.18	
unsown med P		3 13.57			
unsown high P					
aerial low P		4 5.79			
aerial med P		5 17.27			
aerial high P					
sown low P	6 27.48	7 28.25	8 38.05	9 23.97	
sown med P	10 47.91	11 20.28	12 40.06	13 30.14	14 28.15
sown high P	15 30.43	16 16.92	17 33.93	18 35.63	19 26.15

ungrouped 22.16

1-2: ns	1-3: 0.0071	1-4: 0.0147	1-7: 0.0002	2-9: ns
3-11: ns	3-5: ns	4-5: 0.0234	4-7: 0.0082	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: 0.0387
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: 0.0402	17-19: ns	

Vulpia spp. n=297
Untransformed data used
Significance of GLM P<0.0001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.63		2 0.94	
unsown med P		3 9.38			
unsown high P					
aerial low P		4 4.58			
aerial med P		5 8.03			
aerial high P					
sown low P	6 5.98	7 6.57	8 20.65	9 7.49	
sown med P	10 10.01	11 4.66	12 10.55	13 7.22	14 10.79
sown high P	15 2.75	16 8.18	17 12.35	18 5.22	19 12.89

ungrouped 10.01

1-2: ns	1-3: 0.0013	1-4: ns	1-7: 0.0004	2-9: ns
3-11: ns	3-5: ns	4-5: ns	4-7: ns	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: 0.0498	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

CHAMAEPHYTES
Log transformed data used
Significance of GLM P<0.001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 2.44		2 4.50	
unsown med P		3 0.56			
unsown high P					
aerial low P		4 0.76			
aerial med P		5 0.32			
aerial high P					
sown low P	6 0.14	7 1.23	8 0.02	9 0.18	
sown med P	10 0.01	11 0.02	12 0.05	13 0.04	14 0.00
sown high P	15 0.00	16 0.00	17 0.49	18 0.05	19 0.00

ungrouped 0.00

1-2: 0.0023	1-3: 0.0054	1-4: 0.0073	1-7: 0.0052	2-9: 0.0001
3-11: 0.0457	3-5: ns	4-5: ns	4-7: ns	5-11: ns
6-7: ns	6-8: ns	7-9: 0.0412	8-9: ns	6-14: ns
6-10: ns	7-11: 0.0096	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Native chamaephytes
Acaena nova-zelandiae n=32
Log transformed data used
Significance of GLM P<0.01

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.10		2 1.38	
unsown med P		3 0.09			
unsown high P					
aerial low P		4 0.06			
aerial med P		5 0.03			
aerial high P					
sown low P	6 0.13	7 0.65	8 0.00	9 0.09	
sown med P	10 0.00	11 0.01	12 0.01	13 0.01	14 0.00
sown high P	15 0.00	16 0.00	17 0.47	18 0.00	19 0.00

ungrouped 0.00

1-2: 0.001	1-3: ns	1-4: ns	1-7: 0.0266	2-9: 0.0001
3-11: ns	3-5: ns	4-5: ns	4-7: 0.0437	5-11: ns
6-7: ns	6-8: ns	7-9: 0.0421	8-9: ns	6-14: ns
6-10: ns	7-11: 0.0091	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: 0.0434	16-18: ns	17-19: ns	

GEOPHYTES
Native geophytes
Drosera peltata n=32
Log transformed data used
Significance of GLM P<0.001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.64		2 0.04	
unsown med P		3 0.02			
unsown high P					
aerial low P		4 0.02			
aerial med P		5 0.13			
aerial high P					
sown low P	6 0.00	7 0.37	8 0.00	9 0.02	
sown med P	10 0.00	11 0.00	12 0.00	13 0.00	14 0.00
sown high P	15 0.00	16 0.00	17 0.00	18 0.00	19 0.00

ungrouped 0.02

1-2: 0.0025	1-3: 0.0012	1-4: 0.002	1-7: ns	2-9: ns
3-11: ns	3-5: ns	4-5: ns	4-7: 0.0225	5-11: ns
6-7: 0.0138	6-8: ns	7-9: 0.0112	8-9: ns	6-14: ns
6-10: ns	7-11: 0.0083	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

HEMICRYPTOPHYTES FLAT/VERSATILE ROSETTE
Log transformed data used
Significance of GLM P<0.001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 16.82		2 24.74	
unsown med P		3 18.22			
unsown high P					
aerial low P		4 17.48			
aerial med P		5 15.56			
aerial high P					
sown low P	6 13.60	7 19.74	8 5.36	9 24.27	
sown med P	10 8.08	11 17.88	12 5.66	13 15.76	14 9.32
sown high P	15 18.95	16 12.99	17 3.78	18 11.12	19 8.98

ungrouped 7.20

1-2: ns	1-3: ns	1-4: ns	1-7: ns	2-9: ns
3-11: ns	3-5: ns	4-5: ns	4-7: ns	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: 0.0033	6-14: ns
6-10: 0.0435	7-11: ns	8-12: ns	9-13: 0.0105	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: 0.0013
10-12: ns	11-13: ns	12-13: 0.0030	12-14: ns	15-16: ns
15-17: 0.0066	17-18: 0.0033	16-18: ns	17-19: ns	

Native flat/versatile rosette hemicryptophytes
Ehrharta stipoides n=83
Square root transformed data used
Significance of GLM P<0.0001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 5.85		2 10.08	
unsown med P		3 3.98			
unsown high P					
aerial low P		4 3.02			
aerial med P		5 1.28			
aerial high P					
sown low P	6 0.55	7 0.97	8 0.08	9 0.04	
sown med P	10 0.96	11 0.34	12 0.00	13 0.00	14 1.79
sown high P	15 0.00	16 0.00	17 0.00	18 0.00	19 0.00

ungrouped 0.01

1-2: ns	1-3: ns	1-4: 0.0165	1-7: 0.0001	2-9: 0.0001
3-11: 0.0157	3-5: ns	4-5: ns	4-7: ns	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Gnaphalium spp. n=59
Square root transformed data used
Significance of GLM P<0.0001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.39		2 0.87	
unsown med P		3 0.32			
unsown high P					
aerial low P		4 0.33			
aerial med P		5 0.02			
aerial high P					
sown low P	6 0.01	7 0.05	8 0.00	9 0.03	
sown med P	10 0.00	11 0.02	12 0.00	13 0.05	14 0.01
sown high P	15 0.00	16 0.00	17 0.00	18 0.00	19 0.00

ungrouped 0.00

1-2: ns	1-3: ns	1-4: ns	1-7: 0.0006	2-9: 0.0001
3-11: 0.0273	3-5: 0.0428	4-5: 0.0083	4-7: 0.0131	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Oxalis perennans n=125
Log transformed data used
Significance of GLM P<0.0001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 1.06		2 1.26	
unsown med P		3 0.63			
unsown high P					
aerial low P		4 0.70			
aerial med P		5 0.32			
aerial high P					
sown low P	6 0.39	7 0.22	8 0.18	9 0.41	
sown med P	10 0.05	11 0.04	12 0.08	13 0.06	14 0.08
sown high P	15 0.03	16 0.02	17 0.03	18 0.10	19 0.01

ungrouped 0.05

1-2: 0.0407	1-3: ns	1-4: ns	1-7: 0.0001	2-9: 0.0001
3-11: 0.0021	3-5: ns	4-5: 0.0110	4-7: 0.0011	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: 0.0461
6-10: 0.0258	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Solenogyne dominii n=50
Log transformed data used
Significance of GLM P<0.0001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.27		2 0.04	
unsown med P		3 0.02			
unsown high P					
aerial low P		4 0.16			
aerial med P		5 0.35			
aerial high P					
sown low P	6 0.03	7 0.21	8 0.02	9 0.00	
sown med P	10 0.00	11 0.020	12 0.02	13 0.00	14 0.00
sown high P	15 0.00	16 0.00	17 0.00	18 0.00	19 0.00

ungrouped 0.000

1-2: 0.0001	1-3: 0.0001	1-4: ns	1-7: ns	2-9: ns
3-11: ns	3-5: 0.0004	4-5: ns	4-7: ns	5-11: 0.0001
6-7: 0.0158	6-8: ns	7-9: 0.0013	8-9: ns	6-14: ns
6-10: ns	7-11: 0.0067	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Solenogyne gunnii n=53
Log transformed data used
Significance of GLM P<0.0001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.63		2 0.93	
unsown med P		3 1.24			
unsown high P					
aerial low P		4 1.02			
aerial med P		5 0.22			
aerial high P					
sown low P	6 0.11	7 0.01	8 0.00	9 0.00	
sown med P	10 0.00	11 0.01	12 0.01	13 0.00	14 0.00
sown high P	15 0.00	16 0.00	17 0.00	18 0.00	19 0.00

ungrouped 0.00

1-2: 0.0407	1-3: ns	1-4: ns	1-7: 0.0001	2-9: 0.0001
3-11: 0.0001	3-5: 0.0018	4-5: 0.0289	4-7: 0.0002	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Exotic flat/versatile rosette hemicryptophytes
Hypochoeris radicata n=287
Log transformed data used
Significance of GLM P<0.0001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 4.49		2 5.39	
unsown med P		3 2.50			
unsown high P					
aerial low P		4 7.55			
aerial med P		5 4.96			
aerial high P					
sown low P	6 3.26	7 6.43	8 2.65	9 3.03	
sown med P	10 2.83	11 1.50	12 0.37	13 1.74	14 0.49
sown high P	15 0.37	16 3.26	17 0.12	18 0.86	19 0.69

ungrouped 1.65

1-2: ns	1-3: ns	1-4: ns	1-7: ns	2-9: ns
3-11: ns	3-5: ns	4-5: ns	4-7: ns	5-11: ns
6-7: ns	6-8: ns	7-9: 0.0254	8-9: ns	6-14: 0.0249
6-10: ns	7-11: 0.0021	8-12: 0.0120	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: 0.0253	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Leontodon taraxacoides n=249
Log transformed data used
Significance of GLM P<0.0001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 3.33		2 3.46	
unsown med P		3 4.56			
unsown high P					
aerial low P		4 2.77			
aerial med P		5 3.00			
aerial high P					
sown low P	6 3.40	7 6.08	8 1.62	9 6.26	
sown med P	10 0.71	11 4.28	12 0.49	13 2.35	14 0.28
sown high P	15 1.75	16 1.20	17 0.24	18 1.08	19 0.31

ungrouped 0.73

1-2: ns	1-3: ns	1-4: ns	1-7: ns	2-9: ns
3-11: ns	3-5: ns	4-5: ns	4-7: ns	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: 0.0126
6-10: 0.0288	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: 0.0359	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Plantago coronopus n=110
Log transformed data used
GLM not significant

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.27		2 0.02	
unsown med P		3 0.00			
unsown high P					
aerial low P		4 0.31			
aerial med P		5 0.02			
aerial high P					
sown low P	6 1.67	7 0.74	8 0.35	9 0.89	
sown med P	10 0.09	11 1.74	12 0.62	13 1.34	14 1.58
sown high P	15 1.62	16 0.02	17 0.14	18 0.65	19 0.06

ungrouped 0.27

1-2: ns	1-3: ns	1-4: ns	1-7: ns	2-9: ns
3-11: ns	3-5: ns	4-5: ns	4-7: ns	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Plantago lanceolata n=105
Untransformed data used
Significance of GLM P<0.05

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.05		2 0.15	
unsown med P		3 0.20			
unsown high P					
aerial low P		4 0.02			
aerial med P		5 1.65			
aerial high P					
sown low P	6 2.89	7 0.82	8 0.02	9 1.08	
sown med P	10 1.53	11 3.61	12 1.07	13 0.64	14 0.91
sown high P	15 1.46	16 0.20	17 0.04	18 0.37	19 0.20

ungrouped 0.00

1-2: ns	1-3: ns	1-4: ns	1-7: ns	2-9: ns
3-11: 0.0037	3-5: ns	4-5: ns	4-7: ns	5-11: ns
6-7: ns	6-8: 0.0172	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: 0.0079	8-12: ns	9-13: ns	10-15: ns
11-16: 0.0037	12-17: ns	13-18: ns	14-19: ns	10-11: 0.0360
10-12: ns	11-13: 0.0002	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Taraxacum officinale n=88
Log transformed data used
GLM not significant

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.06		2 0.07	
unsown med P		3 0.06			
unsown high P					
aerial low P		4 0.05			
aerial med P		5 0.10			
aerial high P					
sown low P	6 0.03	7 0.10	8 0.08	9 0.05	
sown med P	10 0.00	11 0.23	12 0.06	13 0.11	14 0.04
sown high P	15 0.14	16 0.04	17 0.00	18 0.06	19 0.05

ungrouped 0.13

1-2: ns	1-3: ns	1-4: ns	1-7: ns	2-9: ns
3-11: ns	3-5: ns	4-5: ns	4-7: ns	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: 0.0493
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: 0.0149
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Trifolium repens n=198
Log transformed data used
Significance of GLM P<0.0001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.03		2 0.01	
unsown med P		3 4.70			
unsown high P					
aerial low P		4 0.91			
aerial med P		5 3.56			
aerial high P					
sown low P	6 1.19	7 4.06	8 0.33	9 11.21	
sown med P	10 1.88	11 4.86	12 2.90	13 9.08	14 3.61
sown high P	15 9.27	16 7.42	17 3.12	18 7.82	19 6.64

ungrouped 4.28

1-2: ns	1-3: 0.0237	1-4: ns	1-7: 0.0032	2-9: 0.0005
3-11: ns	3-5: ns	4-5: ns	4-7: ns	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: 0.0011	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: 0.0008	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

HEMICRYPTOPHYTES ERECT ROSETTE
Untransformed data used
Significance of GLM P<0.001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 16.10		2 8.40	
unsown med P		3 9.56			
unsown high P					
aerial low P		4 6.46			
aerial med P		5 9.74			
aerial high P					
sown low P	6 4.77	7 19.07	8 1.33	9 15.21	
sown med P	10 1.29	11 15.06	12 1.01	13 14.76	14 1.99
sown high P	15 0.77	16 4.44	17 0.37	18 4.91	19 1.21

ungrouped 8.36

1-2: 0.0119	1-3: 0.0026	1-4: ns	1-7: ns	2-9: ns
3-11: ns	3-5: ns	4-5: ns	4-7: ns	5-11: ns
6-7: ns	6-8: 0.0496	7-9: ns	8-9: 0.0391	6-14: ns
6-10: 0.0302	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: 0.0028
10-12: ns	11-13: ns	12-13: 0.0326	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Native erect rosette hemicryptophytes
Acaena echinata n=52
Untransformed data used
Significance of GLM P<0.0001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.18		2 0.15	
unsown med P		3 0.07			
unsown high P					
aerial low P		4 0.43			
aerial med P		5 0.03			
aerial high P					
sown low P	6 0.00	7 0.04	8 0.00	9 0.03	
sown med P	10 0.34	11 0.01	12 0.01	13 0.01	14 0.00
sown high P	15 0.00	16 0.00	17 0.00	18 0.012	19 0.00

ungrouped 0.00

1-2: ns	1-3: ns	1-4: 0.0068	1-7: 0.0080	2-9: ns
3-11: ns	3-5: ns	4-5: 0.0001	4-7: 0.0001	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: 0.0313	7-11: ns	8-12: ns	9-13: ns	10-15: 0.0277
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: 0.0331
10-12: 0.0189	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Carex spp n=76
Log transformed data used
Significance of GLM P<0.0001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.44		2 0.28	
unsown med P		3 0.24			
unsown high P					
aerial low P		4 0.82			
aerial med P		5 0.35			
aerial high P					
sown low P	6 0.07	7 0.03	8 0.03	9 0.08	
sown med P	10 0.00	11 0.04	12 0.02	13 0.01	14 0.00
sown high P	15 0.00	16 0.02	17 0.00	18 0.00	19 0.00

ungrouped 0.00

1-2: ns	1-3: ns	1-4: 0.0164	1-7: 0.0001	2-9: 0.0348
3-11: 0.0359	3-5: ns	4-5: 0.0091	4-7: 0.0001	5-11: 0.0061
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Juncus spp. n=119
Log transformed data used
Significance of GLM P<0.1

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.50		2 0.26	
unsown med P		3 0.35			
unsown high P					
aerial low P		4 0.83			
aerial med P		5 0.65			
aerial high P					
sown low P	6 1.43	7 0.71	8 0.13	9 0.97	
sown med P	10 0.03	11 1.11	12 0.07	13 0.64	14 0.30
sown high P	15 0.00	16 0.06	17 0.00	18 0.15	19 0.02

ungrouped 0.58

1-2: ns	1-3: ns	1-4: ns	1-7: ns	2-9: ns
3-11: ns	3-5: ns	4-5: ns	4-7: ns	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: 0.0231	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Plantago varia n=37
Log transformed data used
Significance of GLM P<0.001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.23		2 0.04	
unsown med P		3 0.24			
unsown high P					
aerial low P		4 0.39			
aerial med P		5 0.07			
aerial high P					
sown low P	6 0.00	7 0.00	8 0.00	9 0.01	
sown med P	10 0.01	11 0.00	12 0.00	13 0.00	14 0.00
sown high P	15 0.00	16 0.00	17 0.00	18 0.00	19 0.00

ungrouped 0.02

1-2: 0.0043	1-3: ns	1-4: ns	1-7: 0.0001	2-9: ns
3-11: 0.0132	3-5: ns	4-5: 0.0087	4-7: 0.0010	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Exotic erect rosette hemicryptophytes
Agrostis capillaris n=104
Log transformed data used
Significance of GLM P<0.0001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.25		2 0.68	
unsown med P		3 2.20			
unsown high P					
aerial low P		4 0.00			
aerial med P		5 1.46			
aerial high P					
sown low P	6 0.52	7 6.52	8 0.68	9 8.16	
sown med P	10 0.71	11 10.53	12 0.00	13 11.37	14 1.29
sown high P	15 0.02	16 3.23	17 0.10	18 3.46	19 0.02

ungrouped 1.76

1-2: ns	1-3: ns	1-4: ns	1-7: 0.0023	2-9: ns
3-11: ns	3-5: ns	4-5: ns	4-7: 0.0058	5-11: 0.0261
6-7: 0.0266	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: 0.0015	14-19: ns	10-11: 0.0016
10-12: ns	11-13: ns	12-13: 0.0001	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Poa pratensis n=99
Log transformed data used
Significance of GLM P<0.05

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.02		2 0.02	
unsown med P		3 1.09			
unsown high P					
aerial low P		4 0.07			
aerial med P		5 0.55			
aerial high P					
sown low P	6 0.15	7 0.12	8 0.08	9 0.51	
sown med P	10 0.16	11 0.79	12 0.57	13 0.67	14 0.37
sown high P	15 0.22	16 0.28	17 0.27	18 0.10	19 1.12

ungrouped 0.52

1-2: ns	1-3: 0.0002	1-4: ns	1-7: ns	2-9: ns
3-11: ns	3-5: ns	4-5: ns	4-7: ns	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

HEMICRYPTOPHYES PARTIAL ROSETTE
Untransformed data used
Significance of GLM P<0.1

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 1.13		2 0.58	
unsown med P		3 0.41			
unsown high P					
aerial low P		4 0.86			
aerial med P		5 0.42			
aerial high P					
sown low P	6 2.22	7 0.99	8 0.40	9 0.40	
sown med P	10 1.01	11 0.32	12 1.29	13 1.04	14 0.87
sown high P	15 0.49	16 0.33	17 0.55	18 0.92	19 2.91

ungrouped 0.49

1-2: ns	1-3: ns	1-4: ns	1-7: ns	2-9: ns
3-11: ns	3-5: ns	4-5: ns	4-7: ns	5-11: ns
6-7: ns	6-8: 0.0315	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: 0.0067	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: 0.0017	

Native partial rosette hemicryptophytes
Leptorynchos squamatus n=37
Log transformed data used
Significance of GLM P<0.001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.89		2 0.00	
unsown med P		3 0.02			
unsown high P					
aerial low P		4 0.66			
aerial med P		5 0.15			
aerial high P					
sown low P	6 0.00	7 0.26	8 0.00	9 0.03	
sown med P	10 0.00	11 0.00	12 0.00	13 0.00	14 0.00
sown high P	15 0.00	16 0.00	17 0.00	18 0.00	19 0.00

ungrouped 0.02

1-2: 0.0010	1-3: 0.0010	1-4: ns	1-7: 0.0003	2-9: ns
3-11: ns	3-5: ns	4-5: 0.0326	4-7: 0.0454	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Exotic partial rosette hemicryptophytes
Acetosella vulgaris n=207
Square root transformed data used
Significance of GLM P<0.05

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.13		2 0.54	
unsown med P		3 0.35			
unsown high P					
aerial low P		4 0.17			
aerial med P		5 0.25			
aerial high P					
sown low P	6 2.21	7 0.67	8 0.33	9 0.32	
sown med P	10 1.01	11 0.28	12 1.27	13 1.00	14 0.81
sown high P	15 0.46	16 0.17	17 0.53	18 0.89	19 2.49

ungrouped 0.45

1-2: ns	1-3: ns	1-4: ns	1-7: ns	2-9: ns
3-11: ns	3-5: ns	4-5: ns	4-7: ns	5-11: ns
6-7: ns	6-8: 0.0442	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: 0.0368	

PROTO-HEMICRYPTOPHYTES
Square root transformed data used
Significance of GLM P<0.001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 1.78		2 2.52	
unsown med P		3 0.37			
unsown high P					
aerial low P		4 1.22			
aerial med P		5 0.25			
aerial high P					
sown low P	6 0.70	7 0.18	8 0.05	9 0.12	
sown med P	10 0.10	11 0.59	12 0.02	13 0.01	14 0.00
sown high P	15 0.01	16 0.09	17 0.01	18 0.02	19 0.35

ungrouped 0.12

1-2: ns	1-3: 0.0010	1-4: ns	1-7: 0.0001	2-9: 0.0001
3-11: ns	3-5: ns	4-5: 0.0023	4-7: 0.0040	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: 0.0156	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Native proto-hemicryptophytes
Convolvulus erubescens n=34
Log transformed data used
Significance of GLM P<0.001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.19		2 0.06	
unsown med P		3 0.00			
unsown high P					
aerial low P		4 0.18			
aerial med P		5 0.00			
aerial high P					
sown low P	6 0.14	7 0.01	8 0.03	9 0.00	
sown med P	10 0.08	11 0.03	12 0.00	13 0.00	14 0.00
sown high P	15 0.00	16 0.00	17 0.01	18 0.00	19 0.00

ungrouped 0.00

1-2: 0.0212	1-3: 0.0080	1-4: ns	1-7: 0.0004	2-9: ns
3-11: ns	3-5: ns	4-5: 0.0053	4-7: 0.0065	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: 0.0274
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Dichondra repens n=48
Log transformed data used
Significance of GLM P<0.0001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.95		2 1.63	
unsown med P		3 0.04			
unsown high P					
aerial low P		4 0.49			
aerial med P		5 0.00			
aerial high P					
sown low P	6 0.47	7 0.00	8 0.02	9 0.01	
sown med P	10 0.00	11 0.00	12 0.00	13 0.00	14 0.00
sown high P	15 0.00	16 0.00	17 0.00	18 0.00	19 0.00

ungrouped 0.00

1-2: ns	1-3: 0.0010	1-4: ns	1-7: 0.0001	2-9: 0.0001
3-11: ns	3-5: ns	4-5: 0.0048	4-7: 0.0024	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Geranium spp. n=84
Untransformed data used
Significance of GLM P<0.0001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.42		2 0.54	
unsown med P		3 0.22			
unsown high P					
aerial low P		4 0.48			
aerial med P		5 0.22			
aerial high P					
sown low P	6 0.07	7 0.15	8 0.00	9 0.09	
sown med P	10 0.01	11 0.04	12 0.02	13 0.01	14 0.00
sown high P	15 0.01	16 0.09	17 0.00	18 0.02	19 0.00

ungrouped 0.12

1-2: ns	1-3: 0.0274	1-4: ns	1-7: 0.0006	2-9: 0.0001
3-11: ns	3-5: ns	4-5: 0.0088	4-7: 0.0005	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

HEMICRYPTOPHYTES CAESPITOSE
Square root transformed data used
Significance of GLM P<0.01

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 34.92		2 24.71	
unsown med P		3 19.96			
unsown high P					
aerial low P		4 37.95			
aerial med P		5 27.62			
aerial high P					
sown low P	6 33.98	7 25.75	8 21.16	9 22.88	
sown med P	10 21.45	11 28.18	12 26.20	13 22.73	14 36.52
sown high P	15 31.81	16 34.10	17 28.22	18 33.91	19 33.56

ungrouped 23.15

1-2: ns	1-3: 0.0095	1-4: ns	1-7: ns	2-9: ns
3-11: ns	3-5: ns	4-5: ns	4-7: 0.0391	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: 0.0095	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Native caespitose hemicryptophyte
Danthonia spp. n=158
Log transformed data used
Significance of GLM P<0.0001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 16.23		2 12.67	
unsown med P		3 7.69			
unsown high P					
aerial low P		4 22.27			
aerial med P		5 6.15			
aerial high P					
sown low P	6 11.43	7 9.91	8 6.81	9 2.83	
sown med P	10 1.98	11 1.41	12 0.90	13 0.55	14 4.93
sown high P	15 0.00	16 0.03	17 3.41	18 0.50	19 0.01

ungrouped 2.54

1-2: ns	1-3: 0.0211	1-4: 0.0345	1-7: 0.0001	2-9: 0.0001
3-11: 0.0005	3-5: ns	4-5: 0.0001	4-7: 0.0001	5-11: 0.0090
6-7: ns	6-8: ns	7-9: 0.0235	8-9: ns	6-14: ns
6-10: 0.0042	7-11: 0.0113	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Elymus scaber n=35
Log transformed data used
Significance of GLM P<0.1

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.11		2 1.19	
unsown med P		3 0.24			
unsown high P					
aerial low P		4 0.38			
aerial med P		5 0.17			
aerial high P					
sown low P	6 0.46	7 1.97	8 0.23	9 0.00	
sown med P	10 0.00	11 0.00	12 0.03	13 0.18	14 0.00
sown high P	15 0.00	16 0.00	17 0.00	18 1.09	19 0.00

ungrouped 0.02

1-2: 0.0032	1-3: ns	1-4: ns	1-7: ns	2-9: 0.0015
3-11: ns	3-5: ns	4-5: ns	4-7: ns	5-11: ns
6-7: ns	6-8: ns	7-9: 0.0437	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Lomandra longifolia n=50
Log transformed data used
Significance of GLM P<0.0001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 3.40		2 1.74	
unsown med P		3 2.89			
unsown high P					
aerial low P		4 3.10			
aerial med P		5 0.50			
aerial high P					
sown low P	6 1.13	7 0.21	8 0.00	9 0.26	
sown med P	10 0.01	11 0.00	12 0.16	13 0.00	14 0.00
sown high P	15 0.00	16 0.00	17 0.00	18 0.11	19 0.00

Ungrouped 1.57

1-2: ns	1-3: ns	1-4: ns	1-7: 0.0061	2-9: 0.0002
3-11: 0.0001	3-5: 0.0007	4-5: 0.0008	4-7: 0.0025	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18:0.7684	16-18: ns	17-19: ns	

Poa labillardieri n=64
Log transformed data used
Significance of GLM P<0.0001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 3.47		2 9.33	
unsown med P		3 4.47			
unsown high P					
aerial low P		4 1.82			
aerial med P		5 3.85			
aerial high P					
sown low P	6 2.46	7 0.39	8 1.28	9 0.00	
sown med P	10 0.00	11 0.40	12 0.53	13 0.02	14 0.00
sown high P	15 0.00	16 2.00	17 0.00	18 0.01	19 0.00

ungrouped 1.47

1-2: 0.0199	1-3: 0.0307	1-4: ns	1-7: 0.0091	2-9: 0.0001
3-11: 0.0001	3-5: ns	4-5: ns	4-7: 0.0152	5-11: 0.0112
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Poa rodwayi n=63
Log transformed data used
Significance of GLM P<0.0001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 4.32		2 0.32	
unsown med P		3 0.26			
unsown high P					
aerial low P		4 3.82			
aerial med P		5 0.28			
aerial high P					
sown low P	6 0.01	7 0.03	8 0.00	9 0.07	
sown med P	10 0.00	11 0.01	12 0.00	13 0.00	14 0.01
sown high P	15 0.00	16 0.00	17 0.00	18 0.01	19 0.00

ungrouped 0.00

1-2: 0.0001	1-3: 0.0001	1-4: ns	1-7: 0.0001	2-9: ns
3-11: ns	3-5: ns	4-5: 0.0001	4-7: 0.0001	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Schoenus spp. n=90
Log transformed data used
Significance of GLM P<0.0001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 12.51		2 2.25	
unsown med P		3 1.38			
unsown high P					
aerial low P		4 3.09			
aerial med P		5 4.23			
aerial high P					
sown low P	6 1.87	7 3.15	8 0.06	9 1.07	
sown med P	10 0.01	11 0.12	12 0.02	13 0.07	14 0.00
sown high P	15 0.47	16 0.00	17 0.00	18 0.02	19 0.00

ungrouped 0.61

1-2: 0.0001	1-3: 0.0001	1-4: 0.0001	1-7: 0.0001	2-9: ns
3-11: ns	3-5: ns	4-5: ns	4-7: ns	5-11: 0.0083
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: 0.0404	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Stipa spp. n=42
Log transformed data used
Significance of GLM P<0.001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.86		2 0.41	
unsown med P		3 0.04			
unsown high P					
aerial low P		4 1.35			
aerial med P		5 0.00			
aerial high P					
sown low P	6 0.00	7 0.03	8 0.00	9 0.08	
sown med P	10 0.08	11 0.00	12 0.14	13 0.00	14 0.03
sown high P	15 0.00	16 0.00	17 0.10	18 0.00	19 0.00

ungrouped 0.03

1-2: ns	1-3: 0.0046	1-4: 0.0079	1-7: 0.0008	2-9: ns
3-11: ns	3-5: ns	4-5: 0.0010	4-7: 0.0010	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Themeda triandra n=64
Log transformed data used
Significance of GLM P<0.0001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 7.57		2 1.46	
unsown med P		3 0.37			
unsown high P					
aerial low P		4 1.99			
aerial med P		5 0.32			
aerial high P					
sown low P	6 0.00	7 0.14	8 0.02	9 0.28	
sown med P	10 0.00	11 0.00	12 0.00	13 0.01	14 0.01
sown high P	15 0.00	16 0.00	17 0.00	18 0.00	19 0.00

ungrouped 0.02

1-2: 0.0001	1-3: 0.0001	1-4: 0.0001	1-7: 0.0001	2-9: 0.0220
3-11: ns	3-5: ns	4-5: 0.0281	4-7: 0.0033	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Exotic caespitose hemicryptophytes
Anthoxanthum odoratum n=40
Log transformed data used
Significance of GLM P<0.05

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.16		2 1.26	
unsown med P		3 1.37			
unsown high P					
aerial low P		4 0.00			
aerial med P		5 0.72			
aerial high P					
sown low P	6 0.00	7 1.72	8 0.00	9 0.38	
sown med P	10 0.01	11 1.25	12 0.00	13 1.17	14 0.00
sown high P	15 0.00	16 0.02	17 0.00	18 0.01	19 0.01

ungrouped 0.00

1-2: ns	1-3: ns	1-4: ns	1-7: 0.0156	2-9: ns
3-11: ns	3-5: ns	4-5: ns	4-7: 0.0106	5-11: ns
6-7: 0.0139	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: 0.0481	14-19: ns	10-11: 0.0303
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Dactylis glomerata n=132
Log transformed data used
Significance of GLM P<0.0001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.03		2 0.00	
unsown med P		3 0.04			
unsown high P					
aerial low P		4 0.01			
aerial med P		5 1.85			
aerial high P					
sown low P	6 6.39	7 0.27	8 4.98	9 1.86	
sown med P	10 6.07	11 2.91	12 7.81	13 2.74	14 2.18
sown high P	15 6.10	16 1.59	17 1.80	18 2.19	19 9.72

ungrouped 4.80

1-2: ns	1-3: ns	1-4: ns	1-7: ns	2-9: ns
3-11: ns	3-5: ns	4-5: ns	4-7: ns	5-11: ns
6-7: 0.0139	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: 0.0139	13-18: ns	14-19: 0.0039	10-11: ns
10-12: ns	11-13: ns	12-13: 0.0120	12-14: 0.0254	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: 0.0020	

Holcus lanata n=159
Untransformed data used
Significance of GLM P<0.05

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 1.06		2 2.22	
unsown med P		3 1.26			
unsown high P					
aerial low P		4 3.26			
aerial med P		5 3.42			
aerial high P					
sown low P	6 2.00	7 4.74	8 1.60	9 7.09	
sown med P	10 0.54	11 3.21	12 0.10	13 2.84	14 2.41
sown high P	15 1.73	16 2.72	17 0.62	18 2.03	19 0.06

ungrouped 1.22

1-2: ns	1-3: ns	1-4: ns	1-7: 0.0222	2-9: 0.0178
3-11: ns	3-5: ns	4-5: ns	4-7: ns	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: 0.0057	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: 0.0015	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: 0.0297	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Lolium perenne n=282
Log transformed data used
Significance of GLM P<0.0001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.94		2 0.03	
unsown med P		3 3.96			
unsown high P					
aerial low P		4 1.59			
aerial med P		5 11.69			
aerial high P					
sown low P	6 11.40	7 10.43	8 4.89	9 9.59	
sown med P	10 10.66	11 20.25	12 17.03	13 16.27	14 25.10
sown high P	15 23.88	16 27.72	17 17.91	18 28.64	19 20.44

ungrouped 10.84

1-2: ns	1-3: 0.0238	1-4: ns	1-7: 0.0368	2-9: ns
3-11: 0.0064	3-5: ns	4-5: 0.0041	4-7: 0.0061	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: 0.0250	8-12: 0.0254	9-13: ns	10-15: 0.0216
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: 0.0422
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Phalaris aquatica n=32
Log transformed data used
Significance of GLM P<0.0794

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.00		2 0.00	
unsown med P		3 0.00			
unsown high P					
aerial low P		4 0.00			
aerial med P		5 0.00			
aerial high P					
sown low P	6 0.98	7 0.00	8 0.00	9 0.07	
sown med P	10 2.00	11 0.00	12 0.14	13 0.26	14 1.85
sown high P	15 0.05	16 0.00	17 3.59	18 0.11	19 1.32

ungrouped 0.15

1-2: ns	1-3: ns	1-4: ns	1-7: ns	2-9: ns
3-11: ns	3-5: ns	4-5: ns	4-7: ns	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: 0.0279
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: 0.0088
10-12: 0.0260	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

PHANEROPHYTES
Log transformed data used,
Significance of GLM P<0.001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.08		2 0.06	
unsown med P		3 0.04			
unsown high P					
aerial low P		4 0.04			
aerial med P		5 0.02			
aerial high P					
sown low P	6 0.00	7 0.00	8 0.00	9 0.00	
sown med P	10 0.00	11 0.00	12 0.00	13 0.00	14 0.00
sown high P	15 0.00	16 0.00	17 0.00	18 0.00	19 0.00

ungrouped 0.00

1-2: ns	1-3: ns	1-4: ns	1-7: 0.0006	2-9: 0.0258
3-11: ns	3-5: ns	4-5: ns	4-7: ns	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

UNASSIGNED
Galium spp. n=32
Log transformed data used
Significance of GLM P<0.001

	igneous low rf	igneous high rf	sedim low rf	sedim high rf	alluv low rf
unsown low P		1 0.11		2 0.09	
unsown med P		3 0.00			
unsown high P					
aerial low P		4 0.43			
aerial med P		5 0.00			
aerial high P					
sown low P	6 0.00	7 0.00	8 0.00	9 0.00	
sown med P	10 0.00	11 0.03	12 0.00	13 0.01	14 0.01
sown high P	15 0.00	16 0.00	17 0.00	18 0.00	19 0.00

ungrouped 0.05

1-2: ns	1-3: 0.0181	1-4: 0.001	1-7: 0.0063	2-9: ns
3-11: ns	3-5: ns	4-5: 0.001	4-7: 0.001	5-11: ns
6-7: ns	6-8: ns	7-9: ns	8-9: ns	6-14: ns
6-10: ns	7-11: ns	8-12: ns	9-13: ns	10-15: ns
11-16: ns	12-17: ns	13-18: ns	14-19: ns	10-11: ns
10-12: ns	11-13: ns	12-13: ns	12-14: ns	15-16: ns
15-17: ns	17-18: ns	16-18: ns	17-19: ns	

Chapter 3. The flora and plant communities of Township Lagoon Nature Reserve, Tunbridge, Tasmania.

3.1 Introduction

Township Lagoon Nature Reserve (TLNR), at Tunbridge in the Midlands of Tasmania, is an important remnant dominated by *Themeda triandra*. TLNR is listed on the national estate and, as a nature reserve, is managed by the Department of Environment and Land Management. There is a high concentration of rare and threatened plant taxa in the Midlands (Kirkpatrick *et al.* 1988, Gilfedder 1990), including many species that are not protected in any state reserve outside the TLNR (Kirkpatrick *et al.* 1991*a*). The vegetation and soils of TLNR were surveyed between November 1991 and January 1992. The aims of the survey were to document the species and plant communities present, to relate the plant communities to plant communities throughout the Midlands.

3.2 The study area

TLNR (Fig. 3.1) is an area of approximately 16 ha which was set aside for the expansion of the town of Tunbridge, and remained unallocated crown land until the mid-1980s when its conservation significance was recognised, culminating in its proclamation as a nature reserve. Figs. 3.2 – 3.3 show views of the area.

The climate of the Tunbridge district is dry subhumid cool (Gentilli 1972), characterised by a long warm season and peak rainfall in the spring and autumn. This is one of the lowest rainfall areas in the state, with a mean annual rainfall of 492 mm per annum (Table 3.1). The mean daily minimum temperature for the coldest month is 1.0 °C and mean daily maximum temperature for the warmest month is 24.9 °C (Table 3.1). Annual rainfall for the past few years has been much less than the long-term average indicating the general unreliability of rainfall (Fig. 3.4).

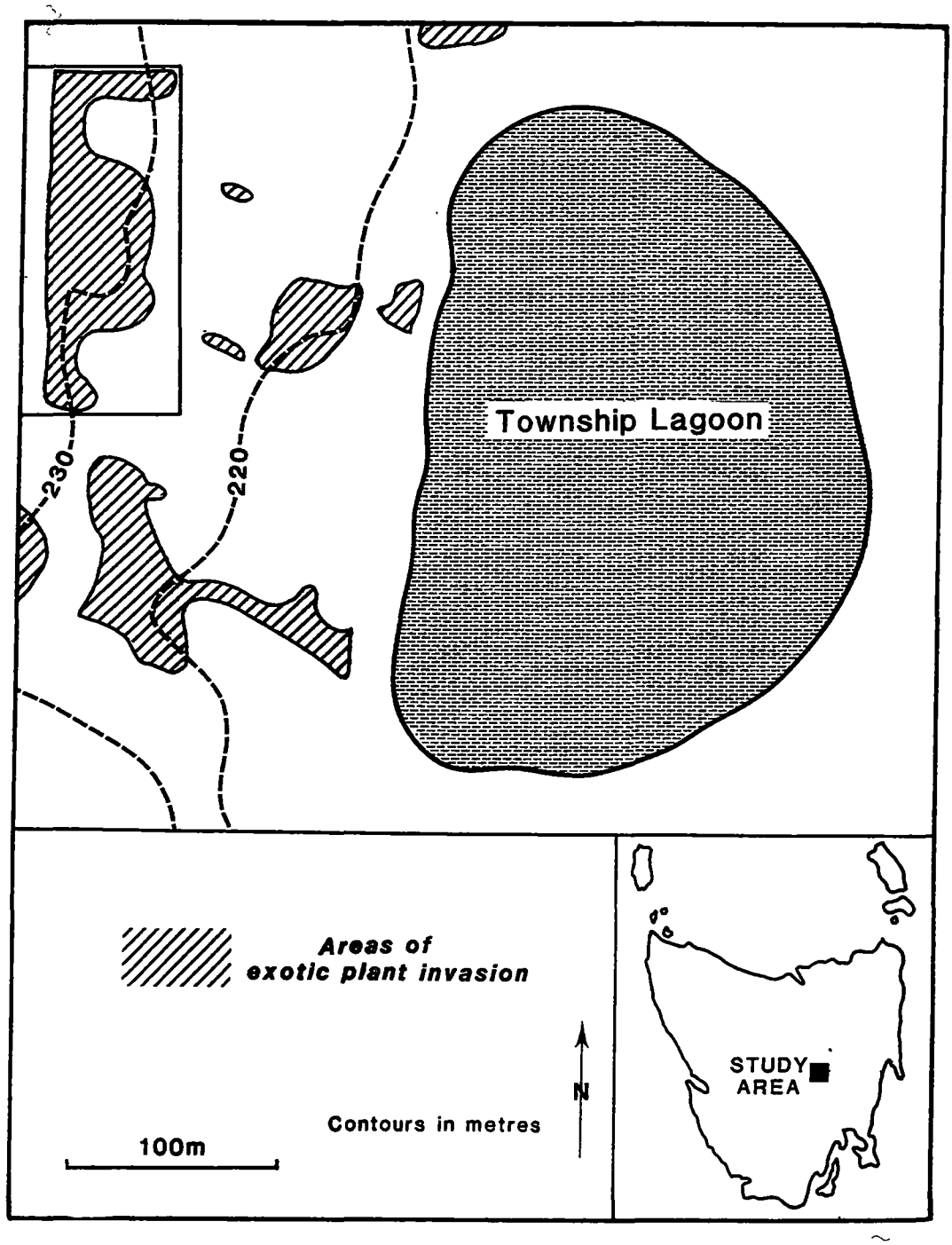

Fig. 3.1. Map of Township Lagoon Nature Reserve at Tunbridge in the Midlands of Tasmania (42°8' latitude, 147°15' longitude)

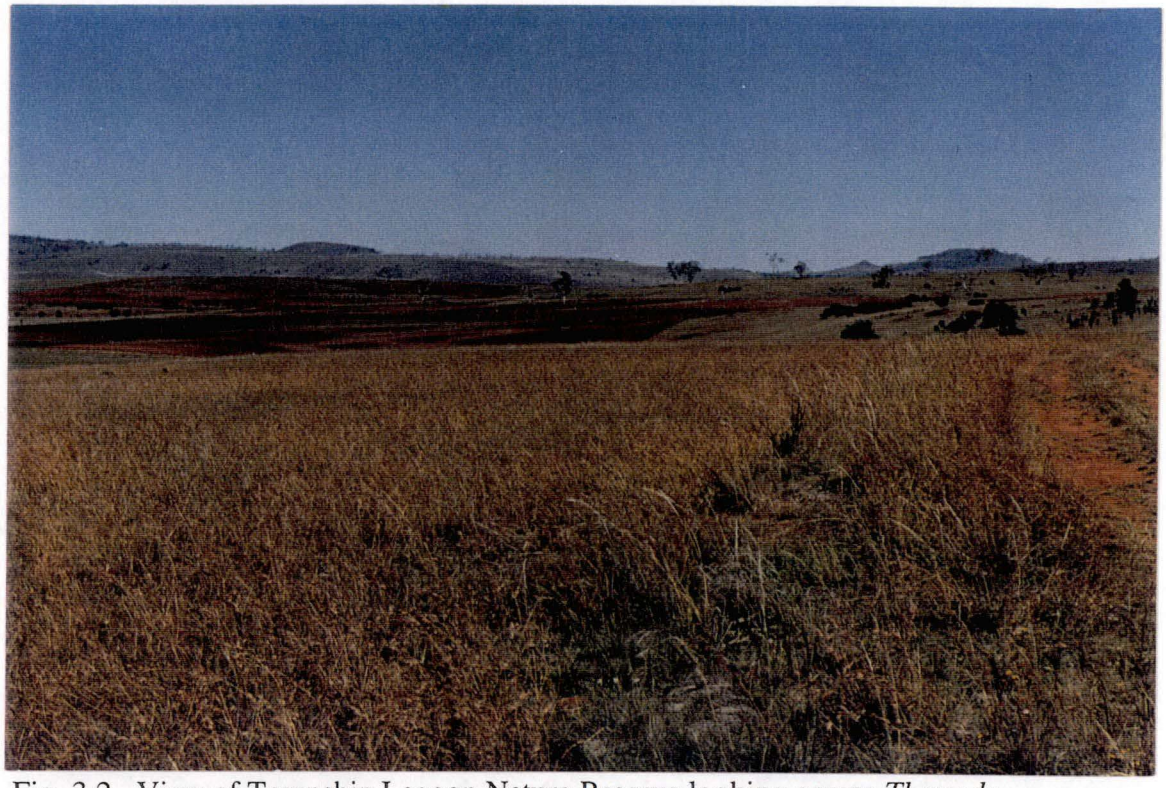

Fig. 3.2. View of Township Lagoon Nature Reserve looking across *Themeda triandra* dominated grassland

Fig. 3.3. View of Township Lagoon Nature Reserve with current refuse disposal site at rear and exotic grassy vegetation in the foreground.

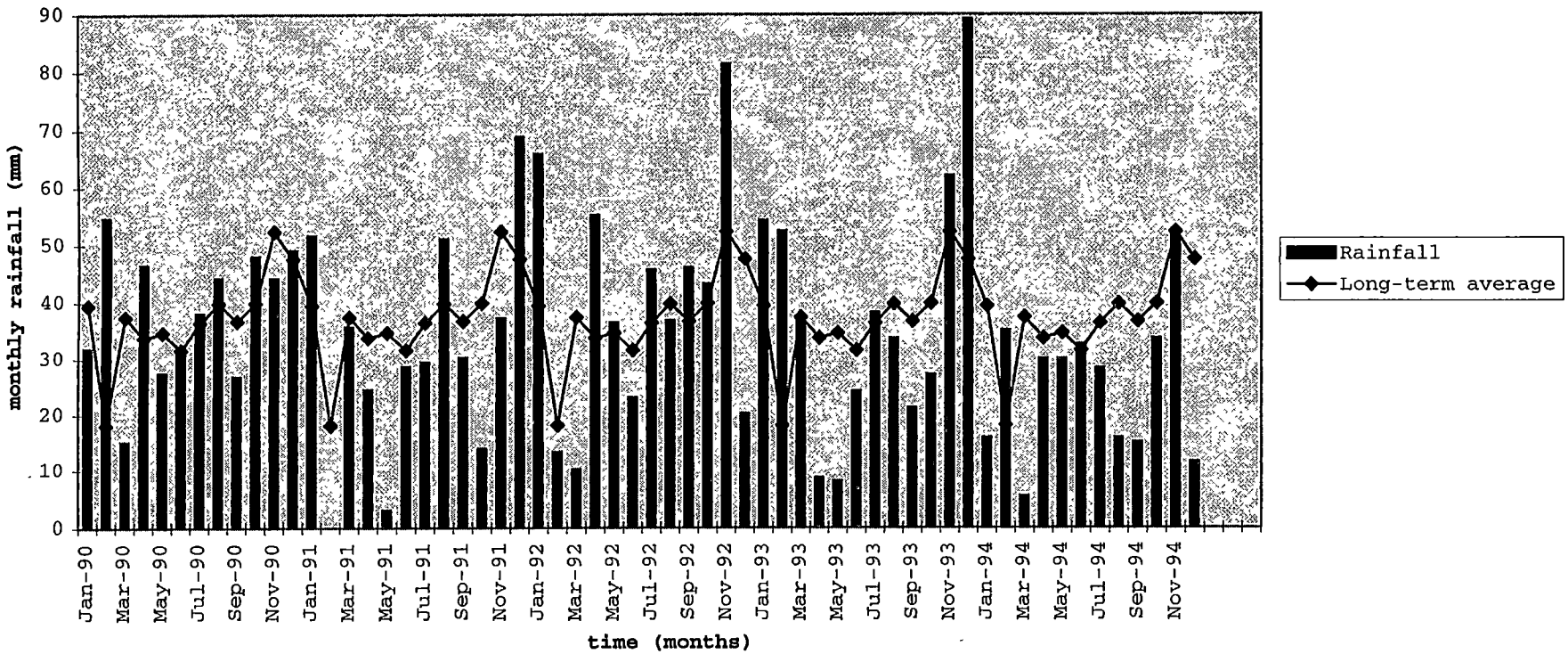

Fig. 3.4. Graph of monthly rainfall (1990 – 1994) and long-term average monthly rainfall (1974-1993) at Township Lagoon Nature Reserve

The geology of TLNR is Tertiary basalt in the elevated areas of the reserve overlying Triassic sediments in the lower areas around and to the east of the lagoon. The site is at approximately 200 – 240 m elevation. The soils consist of shallow medium clay and very dark brown to black duplex clay loam, and are fertile, with moderate to high permeability (Davies 1988).

An early painting of the area indicates that the pre-European vegetation of the TLNR was a treeless grassy plain (Fensham 1989). TLNR was leased for stock grazing until the 1960s and is at present irregularly and lightly grazed. Patches of native grassland and grassy woodland in paddocks adjacent and to the west, south and north of the reserve provide continuous native grassy cover with the vegetation of the nature reserve. In particular, on a hill on adjacent private land to the west of the reserve grassy woodland dominated by *Eucalyptus pauciflora* occurs. Approximately half of the land adjacent to the reserve has been sown to improved pastures or crops.

In the north west corner of the block an area of 1 ha is fenced off and currently used as a refuse disposal site, but in the past more extensive areas were used, and sporadic rubbish dumping in the reserve still occurs. In addition, along the edges of the block, public rights of way exist and these are used for access to adjacent land. Driving of vehicles on the native vegetation and in the dry lagoon bed is common.

TLNR is irregularly burned when fires escape from the adjacent rubbish tip. In 1987 a fire burned most of the area to the west of the lagoon. In December 1993, patches of the grassy vegetation to the west of the lake were subject to a planned burn, and in September 1994 most of the remaining area was burned.

3.3 Methods

Thirty-seven quadrats were located in a stratified random manner in TLNR. Three major vegetation types: saline marginal herbfield; *Themeda triandra* dominated grassland; *Poa labillardierei* dominated grassland and grassland dominated by exotic species, were visually recognised in TLNR. The relative proportions of the

areas of different vegetation types in the reserve were estimated. Quadrats were randomly located within the vegetation types in proportion to the areas of the different vegetation types.

Each quadrat measured 10 x 1 m, and all vascular plant species were recorded both in November 1991 and in January 1992 to maximise the chances of positive identification of species. Species nomenclature follows Buchanan (1995). Slope and aspect were recorded using a clinometer and a compass respectively. Soil pH was determined for each quadrat using a CSIRO soil-testing kit.

The polythetic divisive technique TWINSPAN (Hill 1979) was used to help sort the 10 x 1 m quadrat data into floristic groups using the presence of native species only. With the 10 x 1 m quadrats, two groups were separated on the second division of TWINSPAN, one on the third, and two on the fourth levels. Four quadrats were manually reassigned. The frequencies of species in the quadrats of the floristic groups were calculated. The floristic groups were compared with the plant communities of Kirkpatrick *et al.* (1988).

3.4 Results and discussion

3.4.1 Flora and plant communities

TLNR has been recognised as an important grassland remnant (Kirkpatrick *et al.* 1988, Kirkpatrick *et al.* 1991a). It has a high plant community diversity, ranging from a distinct assemblage of saltmarsh species on the shores of the salt lake, through *Poa* tussock grassland to *Themeda triandra* grassland and grassy woodland. It is also an area of high native plant species richness considering its small area (16 ha). The 116 native species found in TLNR represent approximately 15% of the 750 native plant species of grasslands in Tasmania (Kirkpatrick 1994), while the 71 exotic species present comprise 14% of the total number of exotic species in Tasmania (Table 3.1). The full list of species found at TLNR is given in Appendix 1.

Table 3.1. Number of categories of species found at Township Lagoon Nature Reserve

Category	Number	% of total
Native species	117	62
Introduced species	71	38
Endemic species	3	1.6
Endangered	4	2.1
Vulnerable	3	1.6
Rare	8	4.3
Dicotyledons	124	66
Monocotyledons	63	34
Ferns	1	<1
Total species	188	100

Table 3.2. Geology; soil A horizon texture, colour and pH; slope; aspect and native and exotic species richness of floristic groups determined using TWINSPAN. Means of pH and slope, and means and standard deviations of native and exotic species richness are given. n/a = not applicable

Group	Geology	A horizon	pH	Slope°	Aspect	Native species richness	Exotic species richness
1	sandstone	heavy black clay	9.5	0.5	N-E	3.8±1.3	3.2±2.7
2	sandstone	heavy black clay	9.5	flat	n/a	5.0	6.0
3	dolerite	medium brown clay	6.1	2.3	N-E	6.2±4.8	14.0±4.2
4	sandstone	heavy black clay	6.9	1.7	S-E	17.5±3.1	6.6±1.8
5	dolerite	medium brown clay	6.7	5.5	N-E-S	19.6±4.5	6.9±4.4

Five floristic groups were recognised following the use of TWINSPAN. They are listed below with plant species that were found in at least 40% of the quadrats. In some cases, species that were characteristic of a community but were sporadic in occurrence are included. The soil types, and pH and species richness for the floristic groups, with numbers of quadrats in the groups in parentheses, are listed in Table 3.2.

The floristic groups are as follows:

Floristic Group 1 *Puccinellia stricta* open grassland/herbfield (n=5)
Native graminoids: *Puccinellia stricta*
Native forbs: *Apium prostratum, Isolepis* sp., *Selliera radicans*
Exotic graminoids: *Hordeum marinum*
Exotic forbs: *Plantago coronopus, Leontodon taraxacoides, Spergularia media.*

The vegetation consisted of very low stature, succulent species and exotic rosette herbs near the lake edge, with other species away from the lake in areas of low relief that receive salt spray. There was a high percentage of bare ground, and the soils had heavy black clay A horizons (pH 9) over brown clay B horizons that overlay sandstone.

Floristic Group 2 *Calocephalus lacteus* open grassland (n=1)

Native graminoids: *Danthonia tenuior, Puccinellia stricta*
Native forbs: *Calocephalus lacteus, Selliera radicans, Asperula conferta*
Exotic graminoids: *Hordeum marinum, Lolium perenne*
Exotic forbs: *Leontodon taraxacoides, Plantago coronopus, Trifolium dubium, Scorznera humilis.*

The vegetation in this quadrat represented a distinct floristic group and was located near the lake edge. The vegetation consisted of *Calocephalus lacteus* interspersed with patches dominated by *Danthonia tenuior* with a range of exotic and native

grass and forb species. The soil consisted of a black cracking clay A horizon (pH 9), over brown clay B horizon overlying sandstone, and the ground was flat.

Floristic group 3 *Lolium perenne – Plantago lanceolata* open grassland (n=6)

Exotic graminoids: *Lolium perenne, Bromus hordeaceus, Bromus diandrus, Cynosurus echinatus, Poa bulbosa*
Exotic forbs: *Plantago lanceolata, Cirsium vulgare, Tragopogon porrifolius, Trifolium dubium, Hypochoeris radicata*
Native graminoids: *Danthonia tenuior, Stipa nodosa*
Native forbs: *Asperula conferta.*

Quadrats of this group were found in areas that had been mechanically disturbed or had been subject to refuse dumping. The vegetation was a dense sward dominated by *Lolium perenne* and the annual exotic grasses *Bromus hordeaceus, B. diandrus* and *Cynosurus echinatus*, with native grasses and exotic forbs subdominant. Soils were dark brown clay loam A horizons with evidence of rubbish dumping or mechanical disturbance over dark brown to black medium clay B horizons. Slopes were less than 3° and aspects were north to north east. The vegetation was variable and appeared to be related to the type of disturbance and time since last disturbance.

Floristic group 4 *Poa labillardierei – Dichondra repens* tussock grassland (n=11)

Native graminoids: *Poa labillardierei, Themeda triandra, Danthonia tenuior, Elymus scaber*
Native forbs: *Dichondra repens, Plantago varia, Pimelea humilis, Asperula conferta, Geranium solanderi, Vittadinia muelleri, Acaena echinata, Convolvulus erubescens*
Exotic graminoids: *Cynosurus echinatus*
Exotic forbs: *Plantago lanceolata, Hypochoeris radicata, Centaurium erythraea.*

The vegetation in this group was dominated by *Poa labillardierei* with *Themeda triandra* as a sub-dominant. In areas subject to regular trampling and compaction

by sheep and vehicles *Danthonia tenuior* was dominant. A large diversity of native and exotic forbs and graminoids existed in the intertussock spaces. This group was found to the east and at a low height above the lake on soils with heavy black clay A horizons over brown clay B horizons that overlay sandstone. Slopes were less than 3° and aspects were variable. This is the *Poa labillardierei – Dichondra repens* tussock grassland (Pld) of Kirkpatrick *et al.* (1988).

Floristic group 5 *E. pauciflora – Convolvulus erubescens* grassy woodland (n=14)

Native graminoids: *Themeda triandra, Schoenus absconditus, Danthonia tenuior, Poa rodwayi*
Native forbs: *Geranium solanderi, Chrysocephalum apiculatum, Pimelea humilis, Oxalis perennans, Scleranthus diander, Plantago varia, Asperula conferta*
Exotic graminoids: *Aira caryophyllea, Poa bulbosa*
Exotic forbs: *Centaurium erythraea, Hypochoeris radicata.*

This plant community was widespread in the nature reserve and adjacent native pastures. It was dominated by *Themeda triandra* with a high species richness in the intertussock spaces. *Poa rodwayi* was sub-dominant. *E. pauciflora* was present in the adjacent woodland on private land but was absent from the nature reserve. The soils of quadrats in this group had dark brown clay loam A horizons over dark brown to black medium clay B horizons. The slopes were 0 to 10° and the aspects were north to east. This community corresponds to *Eucalyptus viminalis/E. ovata/E. pauciflora – Convolvulus* erubescens grassy woodland (Evc) of Kirkpatrick *et al.* (1988).

The floristic groups determined using TWINSPAN corresponded with the vegetation types which were recognised initially and were used to stratify the vegetation sampling. This may indicate that the sampling regime has biased the results toward the initially defined vegetation types.

The vegetation of the reserve is diverse, and is determined both by soil and moisture condition and by past disturbance history and current disturbance. There is a lack of detailed knowledge regarding the conservation management of the reserve.

Specifically, knowledge is needed regarding the appropriateness of continued light grazing by sheep, the use of fire, weed management and the rehabilitation of degraded areas within the reserve.

Chapter 4. Comparison of different levels of grazing across fencelines at Township Lagoon Nature Reserve

4.1. Introduction

Grazing is the most important management factor determining the composition of many grassy communities. The level of grazing or grazing pressure strongly affects the composition of grassy vegetation as discussed in Chapter 1.

Assessment of the affects of grazing on plant communities can be experimental or observational. Experimental studies involve the application of defined treatments to experimental plots, where the experimental treatments are randomly allocated to plots. The practical aspects of handling stock for grazing treatments lasting for at least two years were beyond the resource available for this thesis.

In addition, it could be inappropriate to apply a heavy grazing regime in a nature reserve when it is thought to be detrimental. Choosing an already moderately or heavily grazed area as an experimental site raises considerations of the effects of the pre-existing grazing regime.

At TLNR and in the adjoining grazed pastures three levels of grazing on native grassy vegetation are found across intersecting fencelines. This presents an opportunity to examine the effects of three levels of grazing on native grassy vegetation and soil characteristics. The differences in cover of species, life-form groups and major taxonomic groups will be examined. However, the conclusions which can be drawn from the results are limited by the restriction of the study to one place and one time.

4.1.1 Research questions

- Are species, life-forms and major taxonomic groupings different across fencelines?
- Are soil moisture and nutrient conditions different across fencelines?
- Are differences in vegetation caused by different grazing levels or by soil conditions?

4.2 Study area

The study area is the TLNR and adjacent paddocks to the south, west and south west (Fig. 4.1). Figs. 4.2 and 4.3 show views of the area. The study area is located midslope and is well drained. One corner of the reserve was selected where there were three fenced areas across which were three different levels of stock grazing (Fig. 4.1). The vegetation and soils of the reserve and adjoining paddocks are described in Chapter 3.

The area within the TLNR has had a light grazing pressure for several years. It is last known to have been leased for regular grazing at least 20 years ago (pers. comm. W. Triffett), and has been grazed sporadically and at a relatively light intensity since then.

The moderately grazed area has been grazed since early European settlement and at light or moderate intensity for at least 30 years. The stocking rate has been 0.5 DSE ha^{-1}. Part of the area has been ploughed and sown with cereals in recent years. However, the vegetation next to the fence has not been ploughed (W. Triffett, pers. comm.).

The heavily grazed area was an unploughed section of an improved paddock, which has been grazed for a similar period of time and at heavy intensity for several decades. The stocking rate has been the common stocking rate for improved pastures of the region which is approximately 5 DSE ha^{-1} (W. Triffett, pers. comm.). The effective stocking rate, which would have been experienced by the unploughed vegetation, may not have been proportional to the paddock stocking rate, as sheep grazing preference may have been different between the ploughed and unploughed areas of the paddock.

4.3 Methods

4.3.1 Level of grazing

The densities of scats were measured in the three paddocks. Five pairs of 1 m x 1m quadrats were located at 20 m intervals and 5 m from the fencelines. Seep scats on the ground were counted. Where large numbers (> 500 m^{-2}) of scats were present, ten 10 cm x 10 cm squares were sampled. The sum of scats was then multiplied by 10 to estimate a 1 m^2 area.

4.3.2 Soil nutrient status and physical characteristics

Ten soil cores of diameter 2.0 cm and 6.5 cm depth were collected randomly from within each of the 1 x 1 m quadrats using a specially built soil corer. The cores were quickly bagged. The soil from the cores of each quadrat were bulked and mixed.

The samples were taken in spring 1993. The time taken to collect all the samples was approximately 1 hour, and as the weather conditions were overcast, there would not have been a large difference in soil moisture conditions during the collection time.

A subsample of the mixed soil from was weighed before and after air drying overnight in a laboratory. The % loss of weight was taken to be 'as received' soil moisture. The samples were then dried in an oven at 105 °C for 30 min to determine 'air dry' soil moisture (Rayment and Higginson 1992). An approximately 2 gm subsample was taken. Total nitrogen was determined using the Kjeldahl method and total phosphorus by the Vanadomolybdo-phosphoric acid colourimetric method (Jackson 1958).

4.3.3 Ordination of quadrats

The cover values of species were analysed using multi-dimensional scaling (MDS) (Faith *et al.* 1987). Two axes of ordination scores were generated and vectors of bare ground, litter, nitrogen, phosphorus, as received soil moisture, and air dry soil moisture were fitted to the MDS axes.

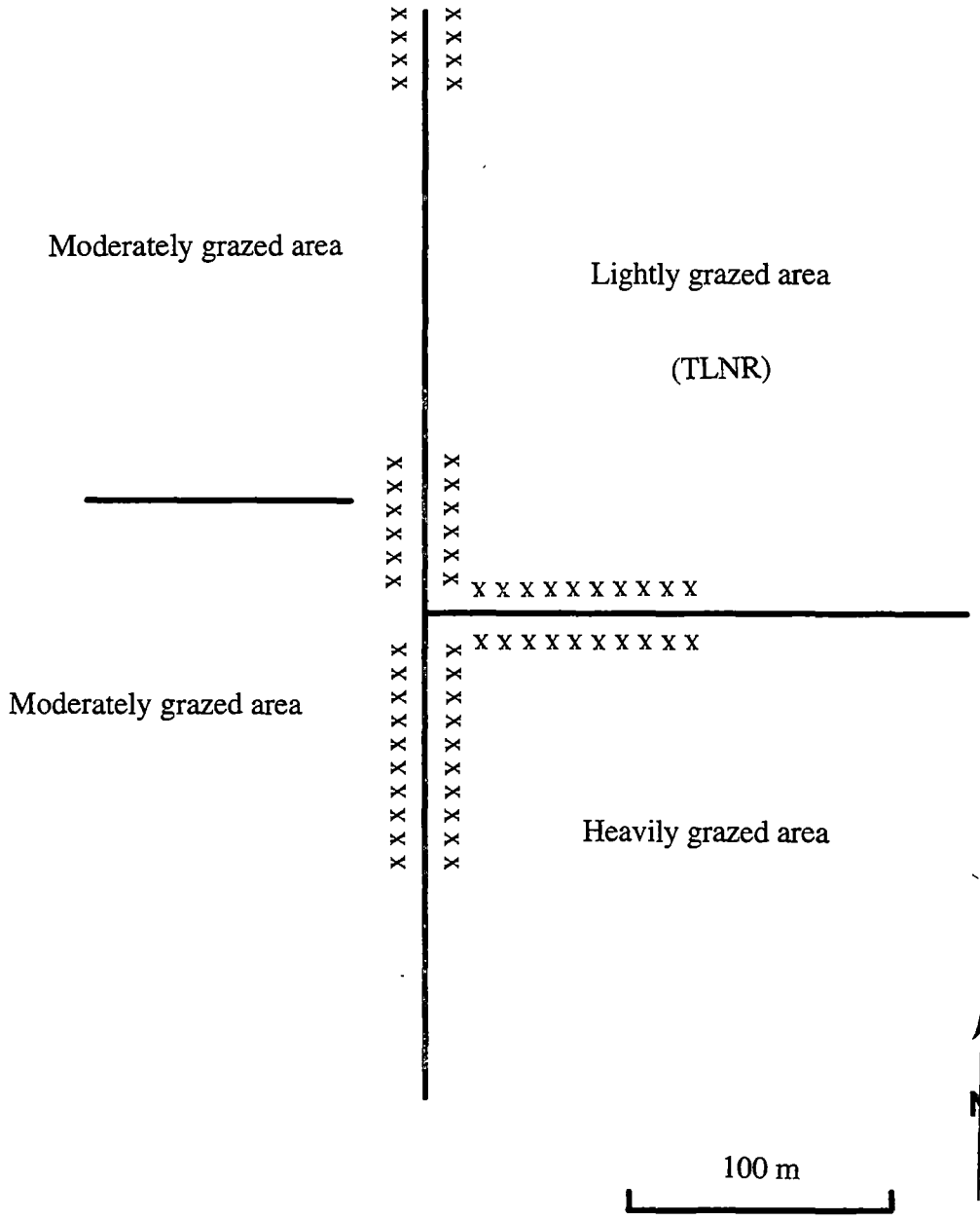

Fig 4.1. Diagram of layout of plots across the fence-lines at Township Lagoon Nature Reserve. Location of plots (x) is not to scale

Fig 4.2. View along fenceline with moderately grazed area on left and lightly grazed area (Township Lagoon Nature Reserve) on right

Fig 4.3. View along fenceline with heavily grazed area on left and moderately grazed area on right

4.3.4 Comparison of paired quadrats

Ten pairs of 1 x 1 m quadrats were located at 10 m intervals on either side and 5 m away from the three fencelines that formed boundaries between the differently stocked areas (Fig. 4.1). The quadrats were all located in areas that had not been ploughed and did not appear to have been subject to mechanical disturbance.

In each quadrat the projective foliage cover to the nearest percentage of all higher plant species was recorded using a 1 x 1m quadrat square divided into 100 units of 10 x 10 cm. The presence of all species present but with < 0.5% cover was recorded as 0.5%. In each quadrat the total cover values of exotic grasses, exotic forbs, native grasses, native forbs, litter, bare ground, moss, lichen, rock and shrubs were recorded.

The cover values of the species and site attributes were entered into the ecological database program, DECODA, and the native and exotic species richness was determined for each quadrat. The total cover of life-form grouping was determined as the sum of taxa of the life-form. The life-form categories are as in Table 2.1.

The use of paired quadrats across the fencelines poses problems in the interpretation of analysis of variance. All the quadrats with the same grazing pressure were located on the same side of the fence. Therefore the different treatments were not randomly allocated. In addition the quadrats are considered to be too close together to be considered replicates. The design consists of sub-sampling rather than true replication.

The design does not satisfy the criteria of hypothesis testing using the standard statistical tests using variance. In this study comparisons of cover in pairs of quadrats across the fencelines are used to indicate the strength of differences between quadrats with different grazing levels rather than testing hypotheses that the cover values are statistically different.

Another problem with the interpretation of the data analysis is the elimination of other factors which may be operating within the treatment units (i.e. across the fence-lines).

Possible factors other than grazing include differences in burning regime, differences in topography, soil depth and texture and moisture, and differences in nutrient inputs (associated with grazing regime).

Therefore it may be possible to rule out some factors although it would never be possible to rule out all factors which may be affecting the vegetation (MacPherson 1990). The results of the data analyses require care in interpretation. Soil moisture and nutrient status are two factors which may have been associated with differences in vegetation, so these were examined.

None of the areas appear to have been burn recently. From the amount of litter present, the TLNR top corner has probably not been burned for at least 10 years, and in other paddocks grazing has reduced the biomass so that in most years the vegetation would be unlikely to carry a fire.

Differences in projective foliage cover between the taxa, levels of litter, bare ground, moss, and shrubs between pairs of quadrats across the fencelines were determined. The differences between log percentage cover values were determined using the formula:

$$\text{log difference} = \log_{10}(\%\ \text{cover}_b + 1\%) - \log_{10}(\%\ \text{cover}_a + 1\%)$$

where $\%\ \text{cover}_a$ = % cover on the side of the fence with the lighter grazing level, and $\%\ \text{cover}_b$ = % cover on the side of the fence with the heavier grazing level.

The log sum of differences of all species belonging to Raunkiaer life-form groups and the major taxonomic groups (exotic grass and graminoid, exotic forb, native grass and graminoid and native forbs) were determined as below:

$$\text{log difference} = \log_{10}(\text{sum of } \%\ \text{cover}_b + 1\%) - \log_{10}(\text{sum of } \%\ \text{cover}_a + 1\%).$$

where $\%\ \text{cover}_a$ = % cover on the side of the fence with the lighter grazing level, and $\%\ \text{cover}_b$ = % cover on the side of the fence with the heavier grazing level.

If a taxon or life-form group was absent from both quadrats of a pair then the species was recorded as being missing from that pair.

The log differences were entered into the SAS statistical package (SAS 1989). Normality of the untransformed and log transformed data were tested by plotting standardised residuals and cumulative probability curves as described in McPherson (1990). The untransformed percentage cover values of almost all taxa appeared not to be normally distributed while log transformed data was normally distributed.

T tests using the GLM procedure of SAS (1989) was used to test whether the differences in cover of species, taxa, life-form groups and major taxonomic groups across the fencelines were significant. However, as the assumptions of analysis of variance in this study are not met, the tests are used to indicate the strength of differences between quadrats with different grazing levels only.

4.4 Results

4.4.1 Level of grazing

All the scats appeared to be from sheep. The density of the scats in the heavily grazed paddock was 5.7 times greater than in the moderately grazed paddock (F = 13.721, P = 0.0016). The density of scats in the moderately grazed paddock was 18.5 times greater than in the lightly grazed paddock (F = 17.085, P = 0.0006) (Table 4.1).

Table 4.1. Means and standard deviations of densities of sheep scats found in quadrats along the fencelines of the three paddocks with low, moderate and high levels of grazing

Comparison of levels of grazing	Mean ± SE	Mean ± SE	Degree of difference	F-value	P
Low to moderate	7.1 ±2 2.1	131.0 ± 103.4	x 18.5	13.721	0.0016
Moderate to high	131.0 ± 103.4	749.0 ± 461.3	x 5.7	17.085	0.0006

The number of scats found would be an estimate of the rate of deposition and would be affected by the rates of decomposition which would vary with different moisture levels

in the paddocks. However, the differences in numbers were likely to have been much larger than differences in decomposition rates.

4.4.2 Soil nutrient status and soil physical characteristics

There were few trends in the level of phosphorus or nitrogen with the level of grazing. Phosphorus was significantly higher in the moderately than in the lightly grazed area ($P<0.0022$), but there were no other significant differences with phosphorus across fencelines. The mean phosphorus level of all the sites in the lightly grazed area was similar to all those in the moderately grazed area. The level of nitrogen was higher in the heavily grazed area than the moderately grazed area ($P<0.0011$). However, there were no other significant differences.

There were also no consistent trends with as received and air dry soil moisture with grazing level. As received soil moisture was significantly lower in the lightly compared to the moderately grazed area, and was significantly higher in the lightly grazed area than in the heavily grazed area (Table 4.2).

4.4.3 Ordination

The vectors of the environmental variables with the highest correlation (r_{max}), with the MDS axes were, in decreasing order of correlation, as received soil moisture, bare ground, air dry soil moisture, ($P < 0.001$) and litter and phosphorus ($P < 0.05$), (Table 4.3). There was no significant vector for nitrogen.

The strength of the vector indicates the importance of increases in bare ground and the associated decreases in soil moisture in determining vegetation composition. The significant but weaker association of phosphorus and the lack of significant association of nitrogen with the ordination axes suggest a relative lack of importance of soil nutrients in this case.

Table 4.2. Comparison of levels of phosphorus, nitrogen, as received and air dry soil moisture across fencelines. Mean values of levels on each side of the fencelines, and means and standard deviations of the differences between pairs of quadrats and P values, are given. ns = not significant

LOW – MODERATE	low grazing	moderate grazing	difference	P
Phosphorus	8.80	11.88	-3.08±0.72	0.0022
Nitrogen	0.278	0.249	0.029±0.0197	ns
As received soil moisture (%)	17.27	23.99	-6.72±1.11	0.0002
Air dry soil moisture (%)	6.22	10.30	-4.07±0.77	0.0005

MODERATE – HIGH	moderate grazing	high grazing	difference	P
Phosphorus	11.14	11.18	-0.04±0.70	ns
Nitrogen	0.329	0.224	0.105±0.022	0.0011
As received soil moisture (%)	10.24	10.55	-0.32±0.46	ns
Air dry soil moisture (%)	5.011	5.587	-0.576±0.257	ns

LOW – HIGH	low grazing	high grazing	difference	P
Phosphorus	13.52	15.85	-2.33±2.34	ns
Nitrogen	0.323	0.319	0.004±0.0289	ns
As received soil moisture (%)	21.02	12.97	8.04±1.00	0.0002
Air dry soil moisture (%)	7.165	6.046	0.759±0.416	ns

Table 4.3. Vector fitting for cross-fence vegetation data based on MDS axes 1 and 2 (2-dimensional). Results of Monte-Carlo significance tests and angles between fitted vectors

				DIRECTION COSINES AND ANGLES OF FITTED VECTORS WITH CONFIGURATION AXES	
SAMPLE	VARIABLE	N	MAX R Prob	1	2
5	litter	60	0.3499 0.020*	0.4245	-0.9054
				64.9	154.9
6	bare	60	0.6261 0.000***	0.4364	0.8998
				64.1	25.9
18	nitrogen	60	0.2051 0.330	-0.7559	-0.6547
				139.1	130.9
19	phosphorus	60	0.3464 0.020*	0.6171	-0.7869
				51.9	141.9
20	airdry soilm	60	0.6039 0.000***	-0.7476	-0.6641
				138.4	131.6
21	asrecv soilm	60	0.7550 0.000***	-0.7678	-0.6406
				140.2	129.8

Angles between fitted vectors (row and columns labels are sequence numbers of fitted sample variables).

	5	16	18	19	20
6	129.0				
18	74.2	166.2			
19	13.0	79.0	87.2		
20	73.5	165.5	0.7	86.5	
21	75.3	167.2	1.1	88.3	1.8

Table 4.4. Mean cover of species, life-forms and site characteristics across three fencelines with low and moderate, low and high and moderate and high grazing levels. < indicates that the species is more abundant and > indicates that the species is less abundant with the higher grazing level of the comparison. ***P < 0.001, **P < 0.01, *P < 0.05. ns indicates no significant difference. Hemi = hemicryptophyte

Species	low grazing (%)	mod grazing (%)	mean diff (%)	P	low grazing (%)	high grazing (%)	mean diff (%)	P	mod grazing (%)	high grazing (%)	mean diff (%)	P
Therophytes	4.15	3.30	-0.85	ns	4.25	2.05	-2.20	>**	2.35	1.90	-0.45	ns
Aira caryophyllea	0.08	0.42	0.34	ns	0.50	0.00	-0.50	ns	0.50	0.00	-0.50	ns
Briza minor	0.43	0.43	0.00	ns	0.50	0.00	-0.50	ns	0.44	0.06	-0.38	>**
Bromus hordeaceus	0.25	0.25	0.00	ns	0.43	0.21	-0.22	ns	0.25	0.50	0.25	ns
Centaurium erythraea	0.69	0.19	-0.50	ns	0.50	0.00	-0.50	ns	0.56	0.19	-0.37	>*
Cirsium vulgare	0.80	0.00	-0.80	ns	0.79	0.07	-0.72	>*	.	.	absent	ns
Cynosurus echinatus	4.63	0.00	-4.63	ns	2.00	0.40	-1.60	>*	0.00	0.50	0.50	ns
Petrorhagia velutina	0.00	0.50	0.50	ns	0.00	0.00	absent	ns	0.20	0.30	0.10	ns
Trifolium dubium	0.40	0.95	0.55	ns	0.57	0.36	-0.21	ns	0.71	0.29	-0.42	ns
Trifolium glomeratum	0.10	0.60	0.50	<*	0.25	0.63	0.38	ns	0.10	0.50	0.40	ns
Trifolium striatum	0.28	0.67	0.39	ns	0.35	0.50	0.15	ns	0.35	0.45	0.10	ns
Trifolium subterraneum	0.00	1.67	1.67	ns	0.00	0.57	0.57	<***	0.06	0.50	0.44	<***
Chamaephytes	1.90	1.40	0.50	ns	4.10	0.15	-3.95	>**	0.90	0.10	0.80	>**
Asperula conferta	1.00	0.40	-0.60	ns	4.50	0.17	-4.33	>**	0.50	0.07	-0.43	>***
Astroloma humifusum	1.60	0.60	-1.00	ns	0.00	0.00	absent	ns	0.00	0.00	absent	ns
Pimelea humilis	0.25	0.75	0.50	ns	0.00	0.00	absent	ns	0.90	0.00	-0.90	>**
Flat/vers rosette hemis	4.77	1.10	-3.67	ns	8.60	2.40	-6.20	>**	0.85	2.65	1.80	<*
Hypochoeris radicata	0.92	0.40	-0.52	ns	1.61	0.22	-1.39	>***	0.36	0.43	0.07	ns
Plantago lanceolata	5.50	0.00	-5.50	ns	6.90	2.00	-4.90	ns	0.00	2.50	2.50	<***
Ptilotus spathulatus	0.33	0.33	0.00	ns	0.00	0.50	0.50	ns	0.20	0.50	0.30	ns
Solenogyne dominii	0.00	1.00	1.00	ns	0.00	0.50	0.50	ns	0.50	0.00	-0.50	ns

Continued next page

Table 4.4. Continued from above page.

Species	low grazing (%)	mod grazing (%)	mean diff (%)	P	low grazing (%)	high grazing r (%)	mean diff (%)	P	mod grazing r (%)	high grazing (%)	mean diff (%)	P
Erect rosette hemis	1.55	1.35	-0.20	ns	1.05	0.00	-1.05	ns	1.55	0.00	-1.55	>**
Acaena echinata	0.17	0.42	0.25	ns	0.50	0.00	-0.50	ns	0.50	0.00	-0.50	ns
Carex breviculmis	0.56	0.78	0.22	ns	2.00	0.00	-2.00	ns	1.10	0.00	-1.10	>**
Plantago varia	1.21	0.21	-1.00	ns	6.00	0.00	-6.00	ns	0.92	0.00	-0.92	ns
Partial rosette hemis	0.44	3.25	2.81	<*	2.33	1.00	0.00	ns	12.44	6.69	-5.75	>*
Leptorynchos squamatus	0.20	1.30	2.14	<***	3.00	1.50	0.00	ns	8.64	7.00	-1.64	ns
Chrysocephalum apiculatum	0.07	2.21	1.10	ns	1.33	0.00	-1.33	ns	4.25	0.38	-3.87	ns
Lomandra nana	0.17	0.67	0.50	ns	0.00	0.00	absent	ns	0.83	0.25	-0.58	ns
Proto-hemis	1.85	1.40	-0.45	ns	1.85	0.90	-1.50	ns	2.10	1.50	-0.60	ns
Convolvulus erubescens	0.42	0.08	-0.34	ns	0.31	0.38	-1.00	ns	0.29	0.29	0.00	ns
Dichondra repens	1.60	0.50	-1.10	ns	2.50	0.00	-0.95	ns	1.44	0.81	-0.63	ns
Geranium solanderi	0.44	0.67	0.23	ns	1.06	0.50	0.07	ns	0.30	0.50	0.20	<*
Vittadinia cuneata	0.00	0.50	0.50	ns	0.25	0.25	-2.50	ns	0.38	0.13	-0.25	ns
Vittadinia muelleri	0.80	0.40	-0.40	ns	0.33	0.33	-0.56	ns	0.60	0.20	-0.40	>*
Caespitose hemis	67.85	43.42	-24.43	>***	48.05	38.00	10.05	ns	28.70	32.74	4.04	ns
Danthonia spp.	1.63	11.20	9.57	<**	5.50	12.60	7.10	ns	9.45	17.19	7.74	ns
Lolium perenne	0.50	0.00	-0.50	ns	0.67	3.25	2.58	ns	0.00	4.25	4.25	ns
Poa bulbosa	0.33	1.33	1.00	ns	0.56	17.89	17.33	<***	0.25	10.90	10.65	<***
Poa rodwayi	3.88	11.06	7.18	<*	22.50	0.00	-22.50	ns	1.33	0.00	-1.33	ns
Schoenus absconditis	0.28	0.89	0.61	<*	0.00	0.00	absent	ns	2.28	0.28	-2.00	>***
Stipa spp.	8.84	8.86	0.02	ns	13.00	7.25	-5.75	ns	3.00	3.10	0.10	ns
Themeda triandra	63.01	20.12	-42.89	>**	30.13	0.06	-30.07	>***	14.83	0.39	-14.44	>*

Continued next page.

Table 4.4. Continued from above page.

Species	low grazing (%)	mod grazing (%)	mean diff (%)	P	low grazing (%)	high grazing r (%)	mean diff (%)	P	mod grazing r (%)	high grazing (%)	mean diff (%)	P
Bare	1.30	9.25	7.95	<*	0.75	8.90	8.15	<**	20.80	14.20	-6.60	ns
Litter	14.40	16.20	1.80	ns	20.30	27.70	7.40	ns	10.25	29.50	19.25	<***
Total plant cover	82.87	55.12	-27.75	>***	68.60	43.85	-24.75	>**	47.00	44.64	-2.36	ns
Exotic forb	5.30	2.25	-3.05	ns	9.10	2.25	-6.85	>**	1.05	2.90	1.85	<**
Exotic grass	2.25	0.90	-1.35	ns	3.15	19.05	15.90	<**	0.50	11.70	11.20	<***
Native forb	3.60	4.50	0.90	ns	6.60	0.90	-5.70	>**	12.60	6.30	-6.30	>**
Native grass	67.5	43.2	-24.30	>***	47.40	19.80	-27.60	>***	29.20	20.80	-8.40	ns
Shrub	1.60	6.30	4.70	<**	2.75	3.25	0.50	ns	4.40	2.00	-2.40	>**

4.4.4 Comparison of vegetation across fencelines

Light to moderate grazing comparison

The vegetation in the lightly grazed area was dominated by rank *Themeda triandra*. In the moderately grazed area a more open and grassy community of lower stature was dominated by *T. triandra*, but with sub-dominant *Danthonia* spp., *Poa rodwayi* and *Stipa* spp (Table 4.4).

The cover values of native grasses and caespitose hemicryptophytes were significantly less in the moderately grazed than the lightly grazed area. *Themeda triandra* was the only species that had significantly less cover in the moderately grazed area, and the differences in native grass and caespitose hemicryptophyte were due largely to the lower cover of *T. triandra*. Total plant cover was less and bare ground was greater in the moderately grazed area than the lightly grazed area. Litter cover was not significantly different (Table 4.4).

The cover of exotic grasses and exotic forbs were not significantly different. The cover of exotic therophytes was not significantly different, however there was variation within the life-form. *T. glomeratum* was the only exotic species that was significantly more abundant in the moderately grazed area compared to the lightly grazed area (Table 4.4).

There were significantly higher levels of native species of low stature including *Danthonia* spp., *Leptorynchos squamatus* and *Schoenus absconditis*, and the taller and more upright *Poa rodwayi* in the moderately grazed area compared to the lightly grazed area (Table 4.4). The presence of these native species indicates their tolerance of the moderate grazing.

Light to heavy grazing comparison

There were a greater number of significant differences in the cover of taxa and life-form groups between the lightly and heavily grazed areas, than between moderately and lightly grazed areas. The vegetation in the lightly grazed area was dominated by tall and

rank *Themeda triandra,* contrasting with the heavily grazed area in which the vegetation was grazed close to the ground and had equal amounts of native and exotic grasses, mainly *Poa bulbosa*, *Danthonia* spp. and *Stipa* spp. *T. triandra* was almost absent in the heavily grazed area (Table 4.4).

Native grasses, native forbs, exotic forbs and total plant cover were significantly less abundant, while exotic grasses were significantly more abundant in the heavily grazed area compared to the lightly grazed area. Most native grasses including *T. triandra*, *Poa rodwayi* and *Stipa* spp. were less abundant in the heavily grazed area compared to the lightly grazed area. *Danthonia* spp., however, were not significantly different (Table 4.4).

The life-form groups that were significantly less abundant within the heavily grazed area than in the lightly grazed area were flat/versatile hemicryptophytes and chamaephytes. The lower amount of the flat/versatile hemicryptophytes was largely due to lesser abundance of *Hypochoeris radicata.* The chamaephyte life-form group, mainly comprising *Asperula conferta,* was significantly less in the heavily grazed area than in the lightly grazed area. There was no overall difference with caespitose hemicryptophyte as *Poa bulbosa* was more abundant and *T. triandra* less abundant in the heavily grazed area compared to the lightly grazed area (Table 4.4).

The therophyte life-form group, comprising exotic grasses and forbs including *Cirsum vulgare* and *Cynosurus echinatus*, were significantly less abundant in the heavily grazed compared to the lightly grazed area (Table 4.4).

Most of the significant differences in the cover of life-form groups appeared to be due to strong differences in particular species which belong to those life-form groups. There appeared to be as much variation between species within the life-form groups as between species of different groups.

Moderate to heavy grazing comparison

There were a large number of differences in species abundance between the moderately grazed and heavily grazed areas. The vegetation in the moderately grazed area consisted

of *Themeda triandra* and *Danthonia* spp. as dominants, a diverse range of native forbs and grasses and a low amount of exotic species cover. The vegetation of the heavily grazed area comprised mainly species of low stature and was dominated by *Danthonia* spp. and *Poa bulbosa* (Table 4.4).

Total plant cover and bare ground were not significantly different. Litter was abundant in the heavily grazed area due to the recent trampling by sheep of grass stems and large amounts of sheep faeces, which were counted as litter.

Exotic grasses and exotic forbs were more abundant and native forbs were less abundant in the heavily grazed area compared to the lightly grazed area. The differences in exotic species were largely due to *Poa bulbosa, Plantago lanceolata* and *Trifolium subterraneum* (Table 4.4).

Some native species, including the very short tufted sedge *Schoenus absconditis* and *Asperula conferta, Carex breviculmis* and *Pimelea humilis,* were less abundant in the heavily grazed area than the moderately grazed area. Native species which did not have significantly less cover in the heavily grazed area included *Leptorynchos squamatus, Chrysocephalum apiculatum* and *Poa rodwayi.*

Life-forms that were less abundant were chamaephytes and erect rosette hemicryptophytes, while the flat/versatile hemicryptophyte life-form was more abundant in the heavily grazed area. There was also variation within the therophyte, caespitose hemicryptophyte and proto-hemicryptophyte life-forms.

4.5 Discussion

The level of grazing appeared to the main factor determining the composition and character of grassy vegetation across the fencelines. However, there are other important factors. Given the limited area sampled and the lack of repeated measurements to assess temporal variation in vegetation the conclusions which could be drawn are limited. The conclusions regarding major taxonomic groups and life-form groups would expected to be more reliable than the conclusions regarding individual species.

The relatively low abundance of a number of native species in the lightly grazed area compared to the moderately grazed area suggests that the release from the competitive dominance of *Themeda triandra* was an important factor in the increase of those species. The increased abundance in the moderately grazed areas of species of lower stature supports this suggestion.

As *Themeda triandra* formed the bulk of the biomass in the lightly grazed area, and was the matrix species (*sensu* Grubb 1986, Collins 1990, Tremont and McIntyre 1994), it would have had a major influence on the growing conditions of the other species. For instance, plants growing in the matrix in the lightly grazed area were taller than across the fences in the moderately and heavily grazed areas.

There were a suite of exotic species including *Cynosurus echinatus* and *Plantago lanceolata* which were largely absent from the moderately grazed area. *Plantago lanceolata* was common in the heavily grazed area, so intolerance of defoliation would not be the reason for its absence from the moderately grazed area. Its lack of abundance in the moderately grazed area may have been due to competitive effects from native species. Although total plant cover was higher in the lightly grazed area, the reduction in insolation and ground wind speed by the *Themeda triandra* tussocks may have created conditions which were more favourable to *Plantago lanceolata.*

Weedy exotic species may have been introduced with past disturbance, and they may have been there due to such conditions as higher soil moisture. The ratio of exotic species cover to total plant cover would indicate that the vegetation in the heavily grazed areas is in poorer condition than in the moderately grazed area.

In the moderately grazed area species richness was higher than the areas with both the higher and lower grazing levels. This is consistent with the intermediate disturbance hypothesis and with Wilson (1990), who found that species richness had a bell-shaped relationship with grazing pressure, and that maximum richness occurred at moderate levels of grazing. On fertile clay and loam soils in Tasmania, similar to Tunbridge, species richness was higher with higher levels of grazing (Kirkpatrick and Fensham 1989).

The reason for the greater abundance of shorter species and smaller tufted grasses is that the perennating buds are protected by being near or below ground level (Tremont 1994). Taller upright growth and budding on the stem of the plant allowing the species to dominate in competition for light, also presents the plant material higher and more easily for browsing.

The life-form groups which were less abundant under the heavier grazing regimes included chamaephytes, phanerophytes and erect rosette hemicryptophytes which have their buds or leaves exposed to grazing. These upright forms were seen to be less abundant under grazing (Noy-Meir *et al.* 1989, Tremont 1993, 1994, McIntyre *et al.* 1995). There was an increase in composition of species from domination by native species to an approximately equal mix of exotic and native species.

In a study of NSW pastures with heavy stocking pressures, no single combination of attributes was related to tolerance of stocking (Rogers 1995). In this study there did not appear be consistent trends in the cover of different life-form groups with heavier grazing. For example, flat/versatile rosette and other sub-groups of hemicryptophytes with very low stature and which may have had protection of the meristems and leaf tissue close enough to the ground to escape grazing did not have a consistent positive response, relative to other groups, to heavier grazing. This suggests that for the species examined in this study the group the life-form classification does not include important factors which affect the responses of species to grazing.

The decline of *Themeda triandra,* rather than complete disappearance in the moderately grazed area, indicates a tolerance of a moderate level of grazing. The moderate level of grazing results in an intermediate stage along a sequence of replacement of tall native perennial grasses by shorter native grasses (Moore 1970). The vegetation subject to the heavy level of grazing is a further stage along the sequence of replacement, where grazing-tolerant *Danthonia* spp. and native forbs of low stature persist.

Fensham and Kirkpatrick (1989) also found that *Themeda triandra* disappeared with heavy grazing. *Themeda triandra* appears unable to cope with the sustained heavy defoliation which exists under common stocking rates in Tasmania. In Africa, heavy grazing increased the mortality of tussocks and decreased seed production (O'Connor

1994), leading to decreased recruitment of soil-stored seed (O'Connor and Pickett 1992, O'Connor 1994).

The lack of a clear trend in the differences in the soil moisture and nutrient conditions between the differently grazed areas suggests that the differences in vegetation are due to the grazing regime.

There was a lack of clear associations between the soil moisture and level of grazing. If greater soil surface evaporation, which would be expected from higher proportion of bare ground, was an important factor, then drier soils would have been detected in the more heavily grazed area.

There was no difference in nitrogen in any of the comparisons. The larger amount of legumes in the moderately grazed area compared to the lightly grazed area (0.7% to 3.9%) would probably have resulted in more nitrogen being fixed in association with the roots of the legumes. The lack of a significantly higher level of nitrogen may have been due to its removal from the system as animal products, meat and wool. However, if removal of nutrients from the system was important then phosphorus would also be lower, opposite to what was found.

As there was no trend of increasing soil nutrients with increased grazing, the competitive advantage of exotic species over native species which was seen at higher nutrient levels (Groves *et al.* 1973, Hobbs and Atkins 1988) would not have been a factor in the increase of exotic species in the heavily grazed areas.

The variation in soil moisture and nutrients cannot be explained in terms of the different grazing levels. Site differences throughout the area are probably important, and the different grazing treatments are superimposed on them. Comparison of different levels of grazing in more uniform vegetation would have been desirable, however, there were no such areas at TLNR.

The description of densities of scats together with the nominal stocking rates indicates relative grazing pressure only. The stocking rate of the moderately grazed area is likely to be lower than regional norms of stocking rate. The high stocking rate is probably similar to the stocking rates of a large proportion of run country. The production of thin

wool fibre by sheep is dependent on a continually low amount of feed being available and stocking rates of sheep on native pastures are generally kept high (approximate 0.5 DSE ha^{-1}).

The sensitivity to stocking rate of some native species in this study indicates its impact. If the addition of nutrients as fertiliser was involved, the effects on the vegetation would be further increased. Grazing behaviour is another important factor in the management.

In conclusion, the three different levels of grazing occurring across the fencelines have resulted in progressive change of species composition. Moderate grazing has not resulted in an overall loss of the native component, but has caused a shift in the native species present compared to areas that were lightly grazed. The heavy grazing regime resulted in the replacement of native species with exotic species and the loss of condition of the native grassy community from a conservation perspective.

There were no clear trends of difference in soil moisture and nutrients across the fencelines, bu there was some variation across the study area. Differences in soil moisture do not appear to b causing the differences in the vegetation.

Chapter 5. Comparison of regrowth of vegetation at Township Lagoon Nature Reserve following burning in different seasons and at different frequencies

5.1 Introduction

5.1.1 Importance of fire in grassy communities

Fire, grazing and rainfall are major factors affecting the composition of grasslands and grassy woodlands worldwide (Gibson and Hulbert 1987). However, often little is known about the ecological effects of fire in those biomes. Fire is an important management tool in grassy communities, and has been for millennia in Australia (Nicholson 1981).

A fire regime is characterised by its components: fire frequency, fire intensity and seasonality of fire. The ecological effects of fire should be investigated in relation to the components. An appropriate fire frequency for a vegetation type depends on climate, fuel accumulation rate and ecology of the biota (Mount 1979).

5.1.2 Seasonality

The seasonality of burning is important, as factors such as life history, morphology and phenological stage determine the severity of effects on plants. In addition, rainfall and other climatic conditions following the burn will affect post-fire survival and regeneration (Gibson and Hulbert 1987, Tolhurst 1995).

Gross changes in vegetation may result from different seasons and burning or changes in species composition may occur where differences between species cause different responses to burning. Burning commonly promotes growth of herbaceous species in grasslands. In North American prairies it is generally agreed that spring fires stimulate grassland production. The effects on herbaceous species are positive for 1 – 2 years (Glenn-Lewin *et al.* 1990).

In a central Australian rangeland, winter fire increased palatable plants while summer fire decreased grasses and increased forbs. Rainfall was important in the response of vegetation following fire (Griffin and Friedel 1984). Similarly, in an open mallee woodland with the grassy cover dominated by *Trioida,* given adequate rainfall, a post-fire pulse of growth occurs (Noble 1989). The regrowth attracts wildlife, and is selectively grazed by stock and wildlife (Noble 1989).

On Hawkesbury sandstone in NSW, recovery from cooler burns in spring was quicker than from hotter burns in autumn. The recovery following spring burns was from resprouting and recruitment, but from autumn burns from recruitment only (Clark 1988).

The timing of burning in relation to the life-cycle stages of the plants is critical as it affects the sensitivity to burning of the plants and subsequent regeneration. Different species will have different requirements. For example, some rare and threatened plants require burning at particular times of the year for reproduction (Scarlett and Parsons 1992).

Fires that occur during the main growing or reproductive phase of plants tend to have the strongest negative effect. Actively growing plants are more susceptible to fire than dormant plants. This has been noted both for fires and drought in the normal growing season of plants (Trollope 1984). The heat of fires that occur before the dispersal of seeds may destroy those seeds. Fires that occur before the growing season may have a promotory effect on species with a vegetative response and which germinate following fire, as the fire provides a period of reduced competition for moisture and light. Ash also provides a post-fire flush of nutrients, however frequent burning can cause nutrient depletion (Ojima *et al.* 1994).

In temperate grasslands in southeastern Australia and the prairies of USA, plants using the C_3 photosynthetic pathway, and with their main growing season in spring and autumn (cool season), co-exist with plants using the C_4 photosynthetic pathway, with their main growing season in summer (warm season). Spring fires generally promote the growth and flowering of C_4 grasses in North America (Glenn-Lewin *et al.* 1990), and disrupt growth and flowering of C_3 grasses (Glenn-Lewin *et al.* 1990).

In South Africa frequent burning in spring promoted dominance of *Themeda triandra*. Fire in summer when *T. triandra* was actively growing had the largest negative effect. However, when *T. triandra* was dormant due to drought there were no differences between burning in midwinter and in spring (Trollope 1984).

Stuwe and Parsons (1977) found that, in native grassland remnants, the highest native species richness occurred on areas where late spring or summer burning and no grazing had occurred. Stuwe (1986) suggested that burning of *T. triandra* dominated grassland in spring would be appropriate, and would increase the warm season C_4 grasses and decrease cool season plants. Burning in spring was not recommended where rare or threatened or otherwise important C_3 plant may be disadvantaged (Stuwe 1986). However, McDougall (1989*a*) considered that the time of burning of *T. triandra* dominated grassland would be critical if an area is burned annually, and that after 2 – 3 burns significant differences could occur.

Howe (1994), criticised the conservation management practices common in North American prairies in which spring burning and exclusion of grazers has caused the over dominance of tall warm season C_4 grasses, to the detriment of smaller and rarer C_4 species. He suggested varying of the seasons of burning and the intervals between burning and re-introducing grazing.

In *Themeda* grassland in Victoria, an autumn fire promoted the germination of annual exotics and resprouters and few native species regenerated (Lunt 1990). Lunt suggested that burning is not a good way on its own to stimulate native regeneration. However, this is not surprising considering that autumn burning occurs when most exotic species are dormant and occurs soon before the growing season. Burning in autumn may create good conditions for an early start for exotic species and stimulate germination of seed and resprouting.

However, in a *Themeda triandra* dominated grassland reserve in Victoria (Derimut), densities of exotics were similar following spring and autumn burning (Robertson 1985)

5.1.3 Intensity

Fire intensity varies greatly with many factors including fuel load, fuel moisture and climatic conditions. Fire intensity may have significant effects on the responses of vegetation following fire.

Standard methodologies exist for the description of fires based on characteristics such as flame height and forward speed of the fire front. The likely intensity of a fire is commonly estimated using the MacArthur fire index slide rule (MacArthur 1982), or the model expressed as equations (Noble *et al.* 1980). Parameters required for calculation are fuel load, fuel moisture and climatic conditions. However, in tropical grasslands, Cheney *et al.* (1993) found that fire spread rate and intensity were not related to fuel load but rather that wind speed had most effect on the rate of fire spread.

The intensity of a fire will increase from ignition to a maximum rate of spread, the maximum rate determined by fuel and climatic conditions. In grasslands, a fire front may take 6 min to reach a steady state and, for a rate of spread 0.5 ms^{-1}, the fire front would travel 180 m (Cheney and Gould 1995).

The intensity of fires in grassy communities will be affected by fuel moisture including that of the standing green biomass and dead plant litter. The greenness of grassy swards varies with the climatic conditions (predominantly rainfall) and the life cycle stage of the plants. Intensities of fires in southeastern Australian grassy communities will usually be higher in autumn than in spring and, when vegetation is greener, the fuel more moist and ambient air and soil temperatures lower.

5.1.4 Frequency

A longer interval between fires allows a greater build up of fuel before the next burn. The interval also allows time for plants to germinate, establish and reach a stage of maturity, growth or reproduction which promotes survival or regeneration following the next burn.

In North American prairies, the longer term effects of frequent fires are to decrease soil organic matter and alter species composition (Ojima *et al.* 1990). It could be expected

that the effects of frequent burning, in different years but in the same season, would be greater than the effects of fewer burns in that season.

5.1.5 Above-ground vegetation

The Australian dry lowland grassland flora has evolved under high frequency fire regimes since Australia became relatively arid.

The hemicryptophyte life-form has the ability to resprout quickly from perennating buds at ground and is thus well adapted to frequent defoliation by fire. A large proportion of the southeastern Australian grassland flora is classified in the hemicryptophyte life-form group (Tremont and McIntyre 1994).

Annual species without large soil-stored seed reserves may be particularly susceptible to burning during their growing season. For many annual species, most of the soil seed reserves germinate at approximately the same time. Therefore, if burning occurs before the seedlings grow to maturity and disperse seed, then soil-stored seed reserves will be greatly reduced. The following year's germination will then be reduced. The seed reserves of some annual species are more persistent and consequently there will a lesser proportion of seed affected by a growing season burn in any particular year.

Bare soils caused by fire may dry out in the upper layers, disadvantaging shallow-rooted species. Many exotic invaders in southeastern Australia are hemicryptophytes that have deep tap roots. The ability of many perennial species to resprout following fire allows those plants to tolerate frequent fire regimes (Christensen and Burrows 1986).

5.1.6 The relative importance of germination and resprouting

Regeneration from seed appears to be common after fire in annual and biennial species, but relatively small numbers of seedlings of perennial species are found (Glenn-Lewin *et al.* 1990).

In a Victorian *Themeda triandra* dominated grassland, all perennial species resprouted following a burn, but only 10 native and 4 exotic perennial species regenerated by

seedlings. Overall, regeneration by seed had much lesser contribution to cover than vegetative reproduction (Lunt 1990). Annual species had large numbers of germinants and germination reflected a seed bank composition which was dominated by exotic species (Lunt 1990). Lunt concluded that burning, where an exotic seed bank is present, is of no benefit to native species richness. However, these results were from a single autumn burn. A burn in early spring might be less favourable to the establishment of exotic annual species.

Exotic seed bank domination is likely to be common in many native grassy communities. However, the abundance of exotic species following burning may occur as a pulse of germination which over 3 – 5 years could prove to be of minor importance.

5.1.7 Experimental burning methodology

There are many difficulties in researching the ecological effects of grassland fires, arising from difficulties in characterising fires, the spatial and temporal variability of fire and vegetation, and practical problems of scale and replication. Fires are difficult to characterise and difficult to control.

Many experiments with burning vegetation are confounded by factors such as grazing by herbivores. In addition, experiments on the frequency of burns may be confounded by the number of burns applied (Trollope 1984). Year-to-year variation between the same season will affect vegetation response (Trollope 1984). Climatic conditions following fire strongly affect post-fire seedling regeneration and resprouting (Tolhurst 1995).

Experimental fires can be fires in small enclosures with adequate replication or cover larger areas but be small in number, with the lack of statistical degrees of freedom that this entails. In addition, the inherent variation in vegetation makes statistical proof of difference difficult to obtain (Glenn-Lewin *et al.* 1990).

In smaller areas, the intensity of fire generally increases with the distance that the fire travels: a fire in a small area will be cooler than one in a larger area. The application of an external heat source such as with a gas burner raises the question of the realism of the soil and surface temperatures that would be achieved.

The simulation of wildfires using external heat sources applied in small plots may be doubtful. The commonly used techniques have tended to produce fires that were complete and more uniform than naturally occurring fires (Glenn-Lewin *et al.* 1990). Therefore Glenn-Lewin *et al.* (1990) concluded that it may not be legitimate to extrapolate effects to larger areas.

5.1.8 Research aims

This chapter examines the effects of differently timed burns and a second consecutive burn on individual species and discusses the effects in terms of life-form classification and phenology of the species. The research questions are:

- Are responses of plant species and life-form groups different following different seasons of burning?
- Are response of species to burning affected by the timing of the burn in relation to the phenology of the species?
- Are the responses of species and life-form groups to a season of burning increased following burning in two consecutive years in the same season?

5.2 Methods

5.2.1 Experimental Design

Experimental plots were established at TLNR in May – June 1992. Initially, a randomised complete block design was used with 30 blocks and 5 plots per block. The vegetation of the blocks varied from native grassland to vegetation with approximately equal cover of native and exotic species. The plot size for the recording of vegetation was 1 m x 1m, the burned areas measured 1.1 m x 1.1 m, and were centered on the recorded area, with an 0.4 m buffer separating them.

Initially the experimental design involved five burn treatments: in winter, early spring, late spring, autumn and no burn (Table 5.1). The five treatments were randomly allocated to the plots in each block (Table 5.2).

Later, increased time became available for conducting the experiment and a second burn in the same season was conducted in 14 of the burned blocks, selected randomly (Table 5.2). The experiment was then regarded as having two factorial treatments: burning season and number of burns (Table 5.1). The experiment ceased to fulfill the criteria of a complete block design and is an incomplete design as not all treatments are represented within the blocks. The experiment was also unbalanced as the number of plots receiving the single burn treatments (16) was higher than the plots receiving the 2 burns (14) which was different from the number of plots which were not burnt (30). The GLM procedure (SAS 1989) is able to analyse both incomplete block designs and the unbalanced data as resulted both from the design of the experiment and the absence from plots of taxa and life-form groups.

Table 5.1. Timetable for recording and burning of quadrats. R indicates recording of the quadrats, B indicates burning and numbers for recording dates in 1993 and 1994 indicate the number of months since burning

Burns	1992			1993				1994	
	Jun	Sep	Nov	Apr	Jun	Sep	Nov	Apr	Dec
Jun x1	RB						R17		R30
Jun x2	RB				B		R4		R17
Sep x1	R	B					R14		R27
Sep x2	R	B				B			R14
Nov x1	R		B				R12		R25
Nov x2	R		B				R12 B		R12
Apr x1	R			B			R7		R20
Apr x2	R			B			R7	B	R7
None	R						R		R
None	R						R		R

Table 5.2. Number of burns of quadrats in blocks and allocation of treatments to blocks. A = winter burn, B = early spring, C = late spring, D = autumn and E = no burn treatment

Block No.	No. of burns	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5
1	2	E	C	A	B	D
2		E	C	B	D	A
3	2	B	D	C	E	A
4		D	A	B	C	E
5	2	B	D	E	C	A
6	2	A	B	C	E	D
7		D	B	A	C	E
8	2	B	E	A	D	C
9		A	B	E	D	C
10		A	C	B	D	E
11		C	B	A	D	E
12	2	A	E	C	D	B
13	2	C	E	A	B	D
14	2	E	A	B	C	D
15	2	E	A	D	B	C
16	2	E	B	C	A	D
17	2	B	C	A	D	E
18	2	B	E	C	D	A
19	2	D	A	B	C	E
20		C	E	D	A	B
21		B	E	A	D	C
22	2	B	E	A	C	D
23		E	C	A	D	B
24		C	B	E	A	D
25		E	C	A	B	D
26	2	E	A	C	D	B
27		E	D	A	C	B
28	2	A	B	C	E	D
29		B	C	D	E	A
30		D	B	E	A	C

5.2.2 Burning

The plots were burned using a method designed to simulate the heat of a wildfire. The heat energy was supplied as oxy-acetylene flame using a 15 cm wide flame head. The flame was directed vertically toward the ground and passed over the surface at a consistent rate of approximately 0.023 ms^{-1}. The flame path was approximately 15 cm wide and 3 minutes were taken to burn each quadrat.

The goal of burning was to scorch all plants to ground level. The rationale behind this was to provide a severe event that would reduce all plants to a similar level. The majority of free-standing plants and plants with low biomass burned quickly. Some flatweeds were slower to burn due to their low stature and the lack of circulation of air and the flame under and around their leaves. The flame was directed for a longer time at these plants. Larger tussocks with buds above ground, but protected from the flame within a mass of live and dead shoots, were not burned completely to the ground at their core but received enough heat from the flame to scorch to the boundary of a perceived central core.

The amount of heat required to do this varied according to the amount of moisture in the vegetation and litter. The burning may not have simulated the behaviour of some wildfires in that in more moist vegetation a wildfire is less likely to burn or would burn with less intensity. However, in some situations, the intensity of a wildfire may be high enough to scorch all the vegetation in an area.

The temperature of the flame was estimated at approximately 1500 °C. On all the burning days in the first year the temperature of the soil at approximately 1 cm was measured using thermocouple wires fused at their ends and a DT100 Data logger. The raw data was downloaded to a portable computer.

A knife was used to cut 1 cm deep slits in the soil of the plots before burning. The slits extended from outside the area to be burned to various places in the quadrat selected without preconceived bias apart from avoiding large tussocks. Any litter that had been present was put aside. The thermocouple wires were carefully inserted into the slits and care was taken to ensure the ends of the thermocouple wires were at approximately 1 cm

depth. The soil on either side of the slits was then pushed together to cover the wires. Litter that had been removed was replaced.

5.2.3 Methodology for plant cover recording

The vegetation of each 1 m x 1 m plot was recorded in June 1992 before the first winter burn, in November 1993, before the second late spring burn and in December 1994 (Table 5.1). In September 1994 a number of the quadrats were burned in an unplanned burn. These were not recorded in December 1994.

The cover of all higher plant species, the sum total of the cover of native grasses, native forbs, exotic grasses, exotic forbs, shrubs, litter, bare ground, moss, rock and rubbish were recorded using a quadrat of 1 m x 1 m divided into one hundred 10 cm x 10 cm units. This allowed the assessment of cover to the nearest 1%. All the estimates of cover were carried out by one observer, the author. The consistency of estimation of percentage cover was tested by estimating and recording the cover of all species in a plot on one day, repeating the estimation of the same plot on the following day without using the previous cover values, and then comparison of the two days' figures. Estimates of cover did not vary by more than 1%.

Total cover of major taxonomic groups, exotic grasses and graminoids, exotic forbs, native grasses and graminoids and native forbs were recorded. Total plant cover, the cover of litter, bare ground, rock and moss were determined.

Data were entered into the ecological database program, DECODA, and the total, exotic and native species richness, exotic and native cover were determined.

5.2.4 Recording of the life history stages of plant species

In unburned quadrats, the phenological stages of all plant species found were recorded. A modified version of the phenological classification in Mueller-Dombois and Ellenberg (1974) was used (Table 5.3). For each quadrat the life history stages of the new germinants and the resprouting individuals of the species were recorded using the code in Table 5.3.

For hemicryptophytes, new shoots of some species emerging from the ground were able to be identified by their morphology, the presence or absence of cotyledons or because the proximity of older plant material indicated that they were new germinants or arising from mature resprouting individuals. In some species this was not able to be determined and these shoots were assumed to be arising from resprouting individuals.

The full range of life history stages which were represented by the species were recorded at 11 dates between June 1992 and December 1994 (Table 5.4). Phenology of the common species was variable. Individuals with varying phenological stages were found within quadrats. For each quadrat, the two most represented phenological stages for mature and resprouting species, and the two most represented phenological stages for seedlings, were recorded. The recordings of the phenological stages for all quadrats in which the species was present were combined. The three most frequently represented stages for the mature and resprouting plants and the three most frequently represented stages for seedlings were determined for each recording date.

Table 5.3. Life history codes used. The codes are a modified version of codes of Mueller-Dombois and Ellenberg (1974)

Plant development		Reproductive development	
0 – 2	first leaf unfolding,	b	budding,
3	two to three leaves unfolded,	fl	flowering,
4 – 5	nearly all leaves unfolded,	fr	fruiting,
6	plant fully developed,	d	dispersing seed.
7	stem or first leaf turning yellow,		
8	< 50% of the shoot system yellow,		
9 – 10	> 50% of the shoot system yellow or the plant dead,		
In addition, for perennial plants, sp indicates the sprouting of new germinants.			

Table 5.4. Dates of quadrat recording and numbers and types of quadrats which were recorded

Dates of recording	Numbers and types of quadrats
03/06/92	30 unburned quadrats
29/07/92	30 unburned quadrats
10/09/92	some unburned quadrats
30/09/92	the remainder of the unburned quadrats
06/11/92	30 unburned quadrats
05/12/92	30 unburned quadrats
05/01/93	30 unburned quadrats
26/04/93	30 unburned quadrats
13/06/93	30 unburned quadrats
21/09/93	16 quadrats burnt in September 1992
24/11/94	20 control quadrats

5.2.5 Methodology for analysis

Comparisons were made of percentage cover between June 1992 and December 1994 for common species, life-form groups, major taxonomic groups, native and exotic species richness and abundance and the site variables: total plant cover, bare ground, litter, rock and moss.

If a species was absent from both of the recordings of the quadrat, then the pair difference was recorded as a missing value. The untransformed, $\log_{10}$ and square root transformed differences in the cover of species and site variables were determined according to formulae below.

difference between log transformed cover values = $\log_{10}(\%\ \text{cover}_b + 1) - \log_{10}(\%\ \text{cover}_a + 1)$

difference between square root transformed values = square root$(\%\ \text{cover}_b + 0.5)$ – square root$(\%\ \text{cover}_a + 0.5)$

where $\%\ \text{cover}_a$ = % initial cover and $\%\ \text{cover}_b$ = % final cover.

If all species belonging of a life-form group were absent from a quadrat at both of the recording times, then the difference in life-form group cover was recorded as a missing value. The untransformed, $\log_{10}$ and square root transformed differences of all species belonging to Raunkiaer life-form groups and the major taxonomic groups: exotic grasses and graminoids, exotic forbs, native grasses and graminoids and native forbs were determined as below.

> difference between log transformed cover values = $\log_{10}$(sum of % $cover_b$ + 1) - $\log_{10}$(sum of % $cover_a$ + 1)
>
> difference between square root transformed values = square root (sum of % $cover_b$ + 0.5) - square root (sum of % $cover_a$ + 0.5)
>
> where % $cover_a$ = % initial cover and % $cover_b$ = % final cover.

The data were analysed as a completely randomised design with 9 treatments. They were:

1. burning in winter 1992;
2. burning in winter 1992 and winter 1993;
3. burning in early spring 1992;
4. burning in early spring 1992 and early spring 1993;
5. burning in late spring 1992;
6. burning in late spring 1992 and late spring 1993;
7. burning in autumn 1993;
8. burning in autumn 1993 and autumn 1994; and
9. and no burning.

The GLM (General Linear Model) procedure of SAS (SAS 1989) was used to compare the changes in cover values of species and life-form groups between June 1992 and November 1994, in the blocks which were not burned in the unplanned fire of September 1994.

Three tests for normality of the data, an assumption of GLM, were conducted for each transformation. The first involved the graphing of standardised residuals versus fitted

values, in which a check was made for changing variability of the residuals with the fitted values. The second test involved the graphing of standardised residuals versus the normal order statistic and a check for non-linear trend line and data points that may be in error. Thirdly, the number of standardised residuals greater than two was noted.

An F test in the GLM procedure was used to test for overall significant differences in least squares means (SAS 1989). The transformation or non transformation that both conformed with the above tests for normality and resulted in the F test with the lowest probability was used to examine the changes in cover values of species and life-form groups.

In cases where the F test did not indicate significant changes in cover overall it is still possible that there are significant differences in the changes in cover between pairs of treatments. Multiple comparisons of groups that were pre-determined to be of interest were made using unrestricted least significant difference (LSD) or multiple t test as recommended by Saville (1990). The significance of an overall F test is not required for the unrestricted LSD to be determined (Saville 1990).

5.3 Results

5.3.1 Description of fire behaviour

The variability of soil temperatures at 1 cm depth was high (Table 5.5). Maximum temperatures recorded at the soil probes varied depending on the initial soil temperature, the duration of flame heating, the depth of the soil probe and the nature of the soil above the probe. The mean maximum temperatures were 61.0 °C in winter and 78.4 °C in autumn. The mean temperature increases above the ambient soil temperatures were higher for autumn burns (62.3 °C) than for the winter burns (52.3 °C) (Table 5.5). The surfaces of the soils were damp to the touch before the winter burn and but dry before the autumn burn. Fig. 5.1 shows the burning occurring and Fig. 5.2 shows regrowth after four months.

5.3.2 Description of weather 1992 – 1994

Mean monthly rainfall for Tunbridge was variable throughout the period 1990 to 1994 (Fig 3.4). During the experimental period it was, at times, much lower than average, including in the periods following the April and September 1993 burns. However, rainfall was high in November and December 1993 (Fig. 3.4).

Table 5.5. Means and standard deviations of soil temperatures measured in quadrats during experimental burns in winter 1992 and autumn 1993. Maximum temperatures recorded and temperatures over which the soil was recorded for 10 seconds, 20 seconds, 30 seconds and 1 minute, and initial soil temperatures are displayed

Season		N	Temperature Mean±SD (°C)	Mean increase (°C)
Winter	maximum	27	61.0±182.6	52.3
	max for 10 sec	27	42.6±100.2	33.9
	max for 20 sec	27	30.0±40.8	21.3
	max for 30 sec	27	24.3±17.9	15.6
	max for 1 min	27	20.6±8.7	11.9
	initial soil temp	27	8.7±2.4	
Autumn	maximum	29	78.4±167.0	62.3
	max for 10 sec	29	51.9±93.1	35.8
	max for 20 sec	29	34.4±21.4	18.3
	max for 30 sec	29	32.4±18.7	16.3
	max for 1 min	29	27.7±15.4	11.6
	initial soil temp	29	16.1±2.2	

Fig. 5.1. Burning an experimental plot with oxy-acetylene flame head in the upper left of the picture

Fig. 5.2. View of regrowth of vegetation in plot (January 1993), four months after burning in September 1992

5.3.3 Life histories of the species

One hundred species were found in the plots (Table 5.5), of which 36 species occurred in 20 or more quadrats (Table 5.6). The most common life–form groups were therophytes, with 10 species in more than 20 quadrats, and caespitose hemicryptophytes, with 8 species.

The variation in phenology was greater than is shown by most commonly recorded phenological stages of the above 36 species (Table 5.7). The method of recording did not allow accurate assessment of the germination and establishment of the species. However, trends in the timing of growth stages of species relative to other species were observed (Table 5.8).

Describing the growth of species relative to others is preferable to describing growth by calendar dates, as variability in seasons makes calendar dates meaningless. For example, from personal observation, the timing of maximum flowering and seed production of *Themeda triandra* can vary up to 2 months in different years, between approximately late December and late February.

Most therophytes germinate and establish, bud, flower and set seed at approximately the same time. Most species were at a similar stage in April 1993, the first recording period for early seedling growth. The median seedling stages of species in June 1993 were less advanced than in June 1992 (Table 5.7).

Most therophytes were at the 2 to 3 leaf stage or more advanced at June 1992. *Trifolium subterraneum* was at more advanced stages of growth than the other species, including other *Trifolium* spp., and was quicker to flower and set seed (Table 5.7).

Aira caryophylla, Briza minor, Cirsium vulgare, Cynosurus echinatus, Trifolium dubium and *Vulpia* spp. were less advanced and were observed at the 3 leaf stage at 27 July 1992 (Table 5.7).

The median time for dispersal of seed was later than early December 1992 (Table 5.7), after the late spring burns in November 1992. Most of the therophytes were at the 2 to 3 leaf stage in June 1992 and nearly all leaves were unfolded by September 1992, before

the early spring burn (Table 5.7). Some seed of *Cynosurus echinatus* and *Cirsium vulgare* would have germinated after June for some species in the control quadrats to be at the 2 leaf stage in late July and September 1992.

Most seed of most therophyte species in normal years would germinate before June and burns at this time would kill most new recruitment. It is likely that few therophytes would be able to successfully recruit in the spring following September burns.

Exceptions to this are *Cirsium vulgare* which germinates over a wider time frame than the other species. In the control quadrats, new germinants of *C. vulgare* were seen following good spring rainfall (Tables 5.7 and 5.8). In the quadrats receiving the burning treatments, *C. vulgare* was commonly seen germinating following burning

The perennial species varied in whether they had dormancy in winter, semi-dormancy or no dormancy; early or later growth in the main growing period (spring); and in the response to late spring/summer rainfall that occurred in 1992 (Table 5.8). Many native forbs grew early in the spring, while native grasses tended to grow later and exotic perennial grasses grew early. However, timing of the growth of exotic perennial forbs varied. Most common exotic perennials responded to the summer rainfall, while native species varied (Table 5.8)..

Table 5.6. Number of occurrences, the transformation applied, and the significance of the GLM, season and number of burn effects and season * burning interaction effects for the % cover of taxa, life-form groups, major taxonomic groups and site variables analysed in burn phenology experiment 94 – 92

	N	Trans-form	GLM	Season	No. of burns	Season * no. of burns
THEROPHYTES	118	log	ns	ns	ns	ns
Aira caryophyllea	22	log	ns	ns	ns	ns
Briza minor	30	log	ns	ns	ns	ns
Bromus hordeaceus	42	log	0.0214	ns	ns	ns
Centaurium erythraea	34	log	0.0014	0.0463	ns	ns
Cirsium vulgare	45	none	ns	ns	ns	ns
Cynosurus echinatus	43	sqrt	ns	ns	ns	ns
Trifolium dubium	47	log	ns	ns	ns	ns
Trifolium striatum	86	none	ns	ns	0.0137	ns
Trifolium subterraneum	88	log	ns	ns	ns	ns
Vulpia spp.	45	log	ns	ns	ns	ns
CHAMAEPHYTES	77	log	ns	ns	ns	ns
Asperula conferta	63	log	ns	ns	ns	ns
FLAT/VERSATILE ROSETTE HEMICRYPTOPHYTES	114	log	ns	ns	ns	ns
Hypochoeris radicata	78	log	ns	ns	ns	ns
Oxalis perennans	35	log	0.0182	ns	0.0125	ns
Plantago lanceolata	22	log	ns	ns	0.0383	ns
Ptilotus spathulatus	23	none	0.0396	0.0046	ns	ns
ERECT ROSETTE HEMICRYPTOPHYTES	115	log	ns	ns	0.0011	ns
Carex breviculmis	110	none	ns	ns	ns	ns
Plantago varia	33	none	ns	ns	ns	ns
Tragopogon porrifolius	36	none	ns	ns	ns	ns
PARTIAL ROSETTE HEMICRYPTOPHYTES	51	none	ns	ns	0.0010	ns
Acaena echinata	51	log	ns	ns	ns	ns
Leptorynchos squamatus	57	log	ns	ns	ns	ns

Table continued next page

Table 5.6. Continued from above page

Chrysocephalum apiculatum	69	log	ns	ns	ns	ns
Lomandra nana	39	log	ns	ns	ns	ns
PROTO-HEMICRYPTOPHYTES	117	sqrt	ns	ns	ns	ns
Convolvulus erubescens	44	none	ns	ns	ns	ns
Geranium solanderi	34	sqrt	0.0024	ns	0.0006	ns
Vittadinia cuneata	33	none	ns	ns	ns	ns
Vittadinia muelleri	53	log	ns	ns	0.0018	ns
CAESPITOSE HEMICRYPTOPHYTES	120	none	0.0215	0.0225	0.0318	ns
Danthonia spp.	44	none	0.0482	ns	0.0044	ns
Elymus scaber	56	log	ns	ns	ns	ns
Lolium perene	45	log	ns	ns	ns	ns
Poa bulbosa	37	log	ns	ns	ns	ns
Poa pratensis	84	none	ns	ns	ns	ns
Schoenus absconditis	89	log	ns	ns	ns	ns
Stipa spp.	88	log	ns	ns	ns	ns
Themeda triandra	95	none	ns	ns	ns	ns
EXOTIC ABUNDANCE	120	none	ns	ns	ns	ns
EXOTIC GRASS	120	none	ns	ns	ns	ns
EXOTIC FORB	120	none	ns	ns	ns	ns
NATIVE ABUNDANCE	120	none	0.0072	0.0135	0.0086	ns
NATIVE GRASS	120	none	0.0097	ns	0.0042	ns
NATIVE FORB	120	none	ns	ns	ns	ns
RICHNESS	120	none	ns	ns	0.0022	ns
NATIVE RICHNESS	120	none	ns	ns	ns	ns
EXOTIC RICHNESS	120	none	ns	ns	0.0035	ns
TOTAL PLANT COVER	120	none	0.0048	ns	0.0003	ns
BARE GROUND	120	none	0.0001	ns	0.0026	ns
LITTER	120	none	0.0496	ns	ns	ns

Table 5.7. Life history states of common species in quadrats. Codes are as in Table 5.3. Phenology was recorded from the unburned quadrats except on 21/09/94 when the spring burnt quadrats were recorded before burning

SPECIES		3/06/92	29/07/92	10/09/92	30/09/92	6/11/92	5/12/92	5/01/93	26/04/93	13/06/93	21/09/93	24/11/94
THEROPHYTES												
Aira caryophyllea			3	4	4,5	6fl,6d	6fr,6d	10d		3	3,2,6	6d
Briza minor			3	4	4,5	6fl,6b	6d,6fr	10d			3	6d
Bromus hordeaceus		3	4	4,5	5,3	6fl,6fr	6fr,6d	10d	3	3	6	6fl,5
Centaurium erythraea		3,4,2	4,3	4	4,3,5	6sp,6fl	2,6b,6fl	6fl,7fr,3	2,3	3,2,4	6	4,5,6fl
Cirsium vulgare		2,3	2,3	2,3	3,2	3,4,6b	6fl,6fr	7,2,3	3,2	3,2	3,2	5
Cynosurus echinatus		2	3,2	3	4,3	6,6fl	6fl,6b	10d,9d	2,3	3,2	3,4,5	6fl
Trifolium dubium		4,3,5	3,2	4,3,5	4,5,3	6fl,6b	6fl,6fr	10d	2,3	2,3	5,4	6fl
Trifolium striatum		3,4,2	4,3	5,4	5,4	6,6fl	6fr,6fl	10d	2,3	2,3	6	5,6,8
Trifolium subterraneum		4,3,5	5,3,4	5,4,6	5,4,6	6fl,6	6d,6fr,6fl	10	3,2	4,3	2,3,4	5,8
Vulpia spp.			3	3	4,3,5	6fl,6b	6fl,6d	10d	3,4	3,4,2	6fl,6	6fl
CHAMAEPHYTES												
Asperula conferta	germin	5,4,2	4,5									
	respr	6sp,6	6sp,6,7	6sp,6fl,6b	6sp,6b	6sp,6fl	6sp,6fl,6fr	6fr,6sp	6sp,6,8	6sp,6,7,8	6sp,6fl	6sp
Pimelea humilis	germin		2,3									
	respr	6	6sp,7	6sp	6b,6sp	6b	6sp	7	6,6sp	6,6sp	6sp	6b
FLAT/VERS ROSETTE HEMICRYPTOPHYTES												
Hypochoeris radicata	germin	3,2,5,4	3,2,4,5	5,4	3,2	3,5,2	5,4,3	5,4,3	3,4,2	4,3,2	3,4,5,2	6,8
	respr	6sp	6sp	6	6	6,6sp	6,6fl	7,6fl,7fl,10	6sp,6	6,8	6sp	6,6sp,8
Leontodon taraxacoides	germin		2,5		4	5,3	5,4	5	3,2	4,5,3	3,4	
	respr	6	6		6sp	6fl	6	6fl,7,7d	6fl,7,6sp	6	6sp	8
Oxalis perennans	germin	2,3,4,5	3,5	5	4,5				3	2		
	respr	6sp	6,7,6sp	6	6sp,6	6sp,6b,6fl	6sp,6,7	7,8	6sp,8,9	6,8	6sp	6sp,8
Plantago lanceolata	germin	4,5	5	5	5	5			4		2,3,4	
	respr	6,7	6,7,6sp	6sp	6sp,6fl,6	6fl,6fr,6sp	6fr,6fl	8d,7d,8fr	6sp,7,8	6,8,7	6sp	6sp,8,6fl

Table continued next page.

Table 5.7. Continued from above page.

Ptilotus spathulatus	germin	3,4	3		5							
	respr	6sp	6sp		6sp	6sp,6	6sp,6fl,6	6fr,7fr,6	6sp	6sp	6	6fl
ERECT ROSETTE HEMICRYPTOPHYTES												
Carex breviculmis	germin											
	respr	6	6sp,6	6,6sp	6fl,6sp,6	6fl,6d,6b	6sp,6d,6fl	6,6fl	6,6sp	6,6sp	6fl,6sp	6fl,6sp
Plantago varia	germin	5	5								4	
	respr	6,6sp	6,6sp,7	6sp,6fl	6sp,6fl	6sp,6,6fl	6sp,7d	7,8d,10	6sp,6	6sp,6	6sp	6sp,6,8
Tragopogon porrifolius	germin										2,3	
	respr	6	6sp		6sp,6	6sp,6b,6fl	6sp,6fl	10,10d,7,6sp	6sp	6sp	6sp	6sp
PARTIAL ROSETTE HEMICRYPTOPHYTES												
Acaena echinata	germin	5,3,2	4						3			
	respr	6sp,6	6sp	6sp,6	6sp	6fl,6sp,6d	6fr,6d	6,6d,7d,7	6sp,6	6,6sp,7	6sp	6sp
Leptorynchos squamatus	germin	4,5	5,6								2,3	
	respr	6sp,6	6sp,6	9	6sp	6b,6fl,6sp	6fl	6d	6sp	6sp,6	6sp	6fl
Chrysocephalum apiculatum	germin	2,5	2,3,4						3			
	respr	6,7,6sp	6sp,6	6sp	6sp	6fl,6b,6sp	6fl	6-9,fl-d	9,8	9,6,8	6sp	6fl
Lomandra nana	germin											
	respr	6,6sp	6sp,6		6sp	6sp,6fr	6fr,6d	7	6,7	6sp,6	6sp	6fl,6sp
PROTO-HEMICRYPTOPHYTES												
Convolvulus erubescens	germin	5,4,3	3,2,5		4,3					2	4	
	respr	6sp,6	6sp		6sp	6sp	6sp,6fl	6fl,6sp,7d	6sp,6fl,8	6sp	6sp	6sp,6fl

Table continued next page.

Table 5.7. Continued from above page.

Geranium solanderi	germin	5,4,3		4,5	4				2		2,3	
	respr	6sp,6	6sp	6sp	6sp	6sp	6fl,6fr,6sp	10,7,10d	6sp	6sp,6,6fl	6sp	8,10
Vittadinia cuneata	germin								2			
	respr	6,6sp	6,6sp	6sp	6sp,6	6sp	6fl,6fr	6fl,6d,6fr	6fl,6	6,6sp	6sp	6b,6sp
Vittadinia muelleri	germin		3				4		2,4	2	2	
	respr	6,6sp	6,6sp	6sp	6sp	6sp,6b	6fl,6b	6d,6fl	6sp,6fl	6sp,6,7	6sp	6sp
CAESPITOSE HEMICRYPTOPHYTES												
Danthonia spp.	germin	5									2,3	
	respr	6,6sp	6,6sp	6sp,6	6sp,6	6fl,6sp,6b	6fl,6b,6fr,6d	6d,8d,7d,10d	7,6,8	8,7,6	6sp	6fl,8
Elymus scaber	germin		2,3									
	respr	6	6,6sp	6sp	6sp	6sp	6fl,6b,6d	6d,6fl,10d	8,7,9	6,8	6sp,6	6sp
Lolium perene	germin	3,5	4							4	5,4	
	respr	6sp,6	6sp	6sp	6sp	6fl,6b,6sp	6fl,6b	7d,9d,8d	6sp,6	6,6sp	6sp	6fl
Poa bulbosa	germin											
	respr	6sp	6sp	6sp	6sp,6fl	10,6fl,6fr,9	10,10fr	10,10d	6sp	6sp,7	6sp	10
Poa pratensis	germin										2	
	respr	6sp,6	6sp	6sp	6sp	6fl	6fl,6fr	10d,7d,7fl	6sp,7,6	6sp	6sp	6sp
Schoenus absconditis	germin											
	respr	6,6sp,7	6sp,6	6sp	6sp,6fl	6fl,6sp	6sp,6fl	7,8	6sp,6	7,6	6sp	6sp,7,8
Stipa spp.	germin			4							4	
	respr	6,7	6sp,6	6sp	6sp,6fl	6fl,6sp	6fl,6b	6d,10d	6,7,8	6,8		6sp
Themeda triandra	germin										3,2	
	respr	6	6	6,6sp	6sp,6	6sp,6b,6fl	6b,6sp,6fl	6fl	6sp,6	8		6sp

Table 5.8. Table of observations of dormancy in winter, time of growth in winter to summer and response to rainfall events. Observations of dormancy level in winter: dormant = less sprouting than non-sprouting, semi-dormant = equal, and non dormant = more sprouting than non-sprouting. Observations of growth in spring: early = begins June, medium = begins August, and late = begins September. Observations of response to summer rainfall: responds = sprouting in January, may respond = sprouting in April but not in January, and does not respond = no sprouting until June

SPECIES	Dormancy in winter	Growth in spring	Response to summer rainfall
THEROPHYTES			
Aira caryophyllea		late	does not respond
Briza minor		late	does not respond
Bromus hordeaceus		medium	does not respond
Centaurium erythraea		medium	does not respond
Cirsium vulgare		late	responds
Cynosurus echinatus		late	responds
Trifolium dubium		late	does not respond
Trifolium striatum		medium	does not respond
Trifolium subterraneum		early	does not respond
Vulpia spp.		late	does not respond
CHAMAEPHYTES			
Asperula conferta	not dormant	early	responds
Pimelea humilis	dormant	medium	may respond
FLAT/VERSATILE ROSETTE HEMICRYPTOPHYTES			
Hypochoeris radicata	semi-dormant	early	may respond
Leontodon taraxacoides	semi-dormant	late	may respond
Oxalis perennans	semi-dormant	early	may respond
Plantago lanceolata	dormant	medium	may respond
Ptilotus spathulatus	not dormant	early	may respond
ERECT ROSETTE HEMICRYPTOPHYTES			
Carex breviculmis	dormant	medium	may respond
Plantago varia	semi-dormant	early	may respond
Tragopogon porrifolius	semi-dormant	late	responds

Table continued next page.

Table 5.8. Continued from above page.

PARTIAL ROSETTE HEMICRYPTOPHYTES			
Acaena echinata	not dormant	early	may respond
Leptorynchos squamatus	not dormant	early	may respond
Chrysocephalum apiculatum	dormant	early	does not respond
Lomandra nana	semi-dormant	early	does not respond
PROTO-HEMICRYPTOPHYTES			
Convolvulus erubescens	not dormant	early	responds
Geranium solanderi	not dormant	early	responds
Vittadinia cuneata	semi-dormant	early	does not respond
Vittadinia muelleri	semi-dormant	early	may respond
CAESPITOSE HEMICRYPTOPHYTES			
Danthonia spp.	dormant	early	does not respond
Elymus scaber	dormant	medium	does not respond
Lolium perene	semi-dormant	early	may respond
Poa bulbosa	not dormant	early	does not respond
Poa pratensis	not dormant	early	may respond
Schoenus absconditis	semi-dormant	early	may respond
Stipa spp.	dormant	medium	does not respond
Themeda triandra	dormant	late	may respond

5.3.4 Responses to different burning treatments

The different treatments have different times elapsed and a different number of growing seasons since burning (Table 5.1). These factors must be taken into account when interpreting the differences in cover of species, groups of species and site variables between the treatments and the control. There were noticeable trends in vegetation response to burning at the different seasons.

Total plant cover increased with time since fire (Fig. 5.3). There is a strong relationship between difference in cover and time since fire with the older burns, however, the 2 x November and the 2 x June burns have lower plant cover than the 2 x April and 2 x September burns respectively. None of the single burn treatments resulted in significantly lower cover than the unburned plots (Table 5.9).

The amount of bare ground decreased with time elapsed since fire. However, the November and September burn treatments had more bare ground than the other treatments with similar elapsed times (Fig. 5.4). Litter cover did not have a clear relationship to time elapsed since fire (Fig. 5.5).

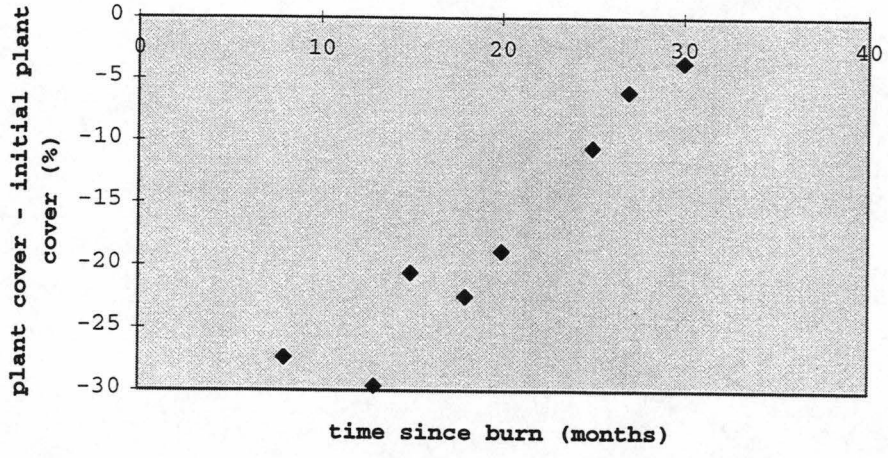

Fig. 5.3 Graph of total plant cover with time since fire following all burns

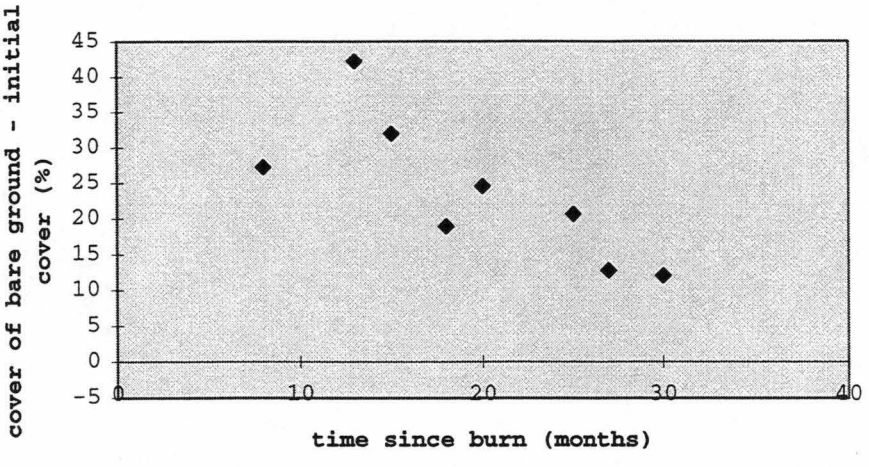

Fig. 5.4 Graph of bare ground with time since fire following all burns

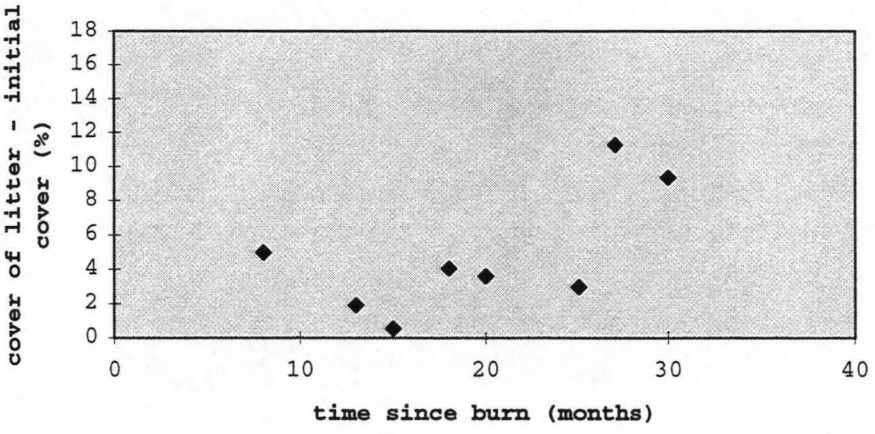

Fig. 5.5 Graph of litter cover with time since fire following all burns

Table 5.9. Means and standard deviations of the change in percentage cover of species, life-form groups and site variables with different seasons of burning and the number of burns. The probability values were determined by pairwise comparisons of least squares means of untransformed, log transformed and square root transformed % cover values. Log and sqrt indicate that logarithmic and square roots transformations of the data were used for determining pairwise comparisons, respectively. For those species back-transformed mean are presented. The month of burning followed by x1 indicates 1 burn, x2 indicates 2 burns, ns indicates a non-significant probability value

THEROPHYTES log

	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	10	-3.200	3.917	.	ns	ns	ns	ns	ns	ns	ns	ns
jun x2	13	-7.154	14.110		.	ns	ns	ns	ns	ns	ns	0.0298
sep x1	10	-5.600	5.420			.	ns	ns	ns	0.0407	ns	0.0070
sep x2	14	-6.493	21.623				.	ns	ns	ns	ns	ns
nov x1	10	-3.900	5.939					.	ns	ns	ns	ns
nov x2	14	-9.000	20.893						.	ns	ns	0.0149
apr x1	11	-0.909	5.843							.	ns	ns
apr x2	14	-4.679	13.083								.	ns
no burn	22	-1.091	6.286									.

Aira caryophyllea log

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	2	0.500	0.000	.	ns	ns		ns		ns	ns	ns
jun x2	2	0.250	0.354		.	ns		ns		ns	ns	ns
sep x1	4	0.250	0.289			.		ns		ns	ns	ns
sep x2												
nov x1	5	0.500	0.354					.		ns	ns	ns
nov x2												
apr x1	4	1.125	1.315							.	ns	ns
apr x2	3	0.500	0.000								.	ns
no burn	2	0.500	0.000									.

Briza minor log

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	3	0.167	0.289	.	ns	ns	ns	ns	ns	ns	ns	ns
jun x2	4	0.125	0.250		.	ns	ns	ns	ns	ns	ns	ns
sep x1	4	0.000	0.000			.	ns	ns	ns	ns	ns	ns
sep x2	1	0.000	.				.	ns	ns	ns	ns	ns
nov x1	3	0.000	0.000					.	ns	ns	ns	ns
nov x2	1	0.000	.						.	ns	ns	ns
apr x1	6	0.250	0.418							.	ns	ns
apr x2	7	0.286	0.267								.	ns
no burn	1	0.500	.									.

Continued next page.

Table 5.9. Continued from above page.

Bromus hordeaceus log

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	5	0.200	0.274	.	ns	ns	ns	ns	ns	ns	ns	0.0022
jun x2	5	0.200	0.274		.	ns	ns	ns	ns	ns	ns	0.0022
sep x1	3	0.000	0.000			.	ns	ns	ns	ns	ns	0.0007
sep x2	4	0.400	0.200				.	ns	ns	ns	ns	0.0405
nov x1	5	0.300	0.274					.	ns	ns	ns	0.0082
nov x2	6	0.250	0.274						.	ns	ns	0.0029
apr x1	2	0.250	0.354							.	ns	0.0294
apr x2	6	0.250	0.274								.	0.0029
no burn	6	1.167	1.080									.

Centaurium erythraea log

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	4	0.125	0.479	.	ns	ns	ns	ns	ns		0.0275	ns
jun x2	4	-0.125	0.250		.	ns	ns	ns	ns		ns	0.0079
sep x1	3	-0.167	0.289			.	ns	ns	ns		ns	0.0107
sep x2	5	0.200	0.274				.	0.0332	0.0401		0.0137	ns
nov x1	3	-0.500	0.000					.	ns		ns	0.0007
nov x2	4	-0.375	0.250						.		ns	0.0006
apr x1												
apr x2	2	-0.750	0.354								.	0.0005
no burn	9	0.833	1.199									.

Cirsium vulgare

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	2	-0.250	0.354	.	ns	ns	ns	ns	ns	ns	ns	ns
jun x2	5	-0.300	0.447		.	ns	ns	ns	ns	ns	ns	ns
sep x1	4	-0.500	0.000			.	0.0288	ns	ns	ns	ns	ns
sep x2	4	0.500	1.683				.	0.0217	0.0449	0.0342	0.0449	0.0342
nov x1	5	-0.500	0.354					.	ns	ns	ns	ns
nov x2	6	-0.333	0.258						.	ns	ns	ns
apr x1	7	-0.357	0.378							.	ns	ns
apr x2	6	-0.333	0.683								.	ns
no burn	7	-0.357	0.378									.

Cynosurus echinatus sqrt

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	2	0.250	2.475	.	ns	ns	ns	ns	ns	ns	ns	ns
jun x2	7	-2.643	4.634		.	ns	ns	ns	ns	0.0178	ns	0.0330
sep x1	3	-1.333	1.528			.	ns	ns	ns	ns	ns	ns
sep x2	4	-1.625	1.702				.	ns	ns	0.0402	ns	ns
nov x1	1	-2.500	.					.	ns	ns	ns	ns
nov x2	7	-0.571	1.205						.	ns	ns	ns
apr x1	3	2.000	4.359							.	ns	ns
apr x2	4	0.000	0.577								.	ns
no burn	12	0.167	1.285									.

Continued next page.

Table 5.9. Continued from above page.

Trifolium dubium log

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	4	0.250	0.289	.	ns	ns	ns	ns	ns	ns	ns	ns
jun x2	1	0.000	.		.	ns	ns	ns	ns	ns	ns	ns
sep x1	6	0.250	0.274			.	ns	ns	ns	ns	ns	ns
sep x2	5	0.400	0.224				.	ns	ns	ns	ns	ns
nov x1	4	0.125	0.479					.	ns	ns	ns	ns
nov x2	6	0.083	0.376						.	ns	ns	ns
apr x1	7	-0.214	1.468							.	ns	ns
apr x2	4	0.000	0.408								.	ns
no burn	10	0.250	0.354									.

Trifolium striatum

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	7	0.643	0.244	.	ns	ns	ns	ns	ns	ns	ns	ns
jun x2	5	2.400	4.827		.	0.0043	0.0237	0.0202	ns	0.0202	ns	0.0176
sep x1	9	-0.167	1.639			.	ns	ns	0.0445	ns	ns	ns
sep x2	9	0.389	0.220				.	ns	ns	ns	ns	ns
nov x1	9	0.333	0.250					.	ns	ns	ns	ns
nov x2	10	1.300	2.429						.	ns	ns	ns
apr x1	9	0.333	0.250							.	ns	ns
apr x2	11	0.955	1.234								.	ns
no burn	17	0.471	0.450									.

Trifolium subterraneum log

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	9	-5.056	3.729	.	ns	ns	ns	ns	ns	ns	ns	ns
jun x2	10	-7.850	15.235		.	ns	ns	ns	ns	ns	ns	ns
sep x1	8	-6.750	6.153			.	ns	ns	ns	ns	ns	ns
sep x2	11	-6.682	17.895				.	ns	ns	ns	ns	ns
nov x1	8	-5.438	6.582					.	ns	ns	ns	ns
nov x2	11	-8.000	11.653						.	ns	ns	ns
apr x1	8	-3.375	4.534							.	ns	ns
apr x2	8	-9.563	16.165								.	ns
no burn	15	-5.200	8.821									.

Vulpia spp. log

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	6	0.500	0.316	.	ns	ns	ns	ns	ns	ns	ns	ns
jun x2	4	0.875	0.750		.	ns	ns	ns	ns	ns	ns	ns
sep x1	3	0.500	0.000			.	ns	ns	ns	ns	ns	ns
sep x2	3	0.500	0.000				.	ns	ns	ns	ns	ns
nov x1	6	0.333	0.258					.	ns	ns	ns	ns
nov x2	5	0.500	0.354						.	ns	ns	ns
apr x1	6	0.500	0.000							.	ns	ns
apr x2	6	0.917	1.068								.	ns
no burn	6	2.917	5.928									.

Continued next page.

Table 5.9. Continued from above page.

CHAMAEPHYTES log

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	6	-0.583	10.047	.	ns	ns	ns	ns	ns	ns	ns	ns
jun x2	11	0.409	2.289		.	ns	ns	ns	ns	ns	ns	ns
sep x1	7	1.429	4.568			.	ns	ns	ns	ns	ns	ns
sep x2	8	-1.000	1.773				.	ns	ns	ns	ns	ns
nov x1	6	-3.000	6.693					.	ns	ns	ns	ns
nov x2	13	-0.154	1.049						.	ns	ns	ns
apr x1	7	-2.929	10.474							.	ns	ns
apr x2	7	-1.071	0.838								.	ns
no burn	12	-1.792	6.946									.

Asperula conferta log

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	4	-4.750	7.309	.	0.0367	ns	ns	ns	0.0445	ns	ns	ns
jun x2	9	0.333	2.550		.	ns	ns	ns	ns	ns	ns	ns
sep x1	6	-0.333	2.563			.	ns	ns	ns	ns	ns	ns
sep x2	8	-0.938	1.821				.	ns	ns	ns	ns	ns
nov x1	3	-6.000	9.179					.	ns	ns	ns	ns
nov x2	10	0.050	1.117						.	ns	ns	ns
apr x1	6	-3.917	10.828							.	ns	ns
apr x2	6	-0.667	0.876								.	ns
no burn	11	-1.955	7.154									.

FLAT/VERSATILE ROSETTE HEMICRYPTOPHYTES log

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	10	-2.350	5.302	.	ns	ns	ns	ns	ns	ns	ns	ns
jun x2	14	-3.786	10.065		.	ns	ns	ns	ns	ns	ns	ns
sep x1	10	-1.800	3.846			.	ns	ns	ns	ns	ns	ns
sep x2	14	-1.857	3.810				.	ns	ns	ns	ns	ns
nov x1	9	-1.000	3.132					.	ns	ns	ns	ns
nov x2	13	-2.115	5.257						.	ns	ns	ns
apr x1	11	-2.318	3.868							.	ns	ns
apr x2	12	-2.833	5.982								.	ns
no burn	21	-4.310	10.651									.

Hypochoeris radicata log

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	5	0.100	1.294	.	ns	ns	ns	ns	ns	ns	ns	ns
jun x2	8	-0.188	1.624		.	ns	ns	ns	ns	ns	ns	ns
sep x1	8	-0.625	1.458			.	ns	ns	ns	ns	ns	ns
sep x2	10	-0.250	1.087				.	ns	ns	ns	ns	ns
nov x1	7	-1.000	2.901					.	ns	ns	ns	ns
nov x2	8	0.125	0.443						.	ns	ns	ns
apr x1	8	-0.938	2.290							.	ns	ns
apr x2	8	-0.313	0.372								.	ns
no burn	16	-0.438	0.834									.

Continued next page.

Table 5.9. Continued from above page.

Oxalis perennans log

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	3	0.167	0.289	.	ns	ns	0.0329	ns	0.0018	ns	ns	ns
jun x2	3	-2.500	3.279		.	ns	ns	ns	0.0307	ns	ns	ns
sep x1	4	1.500	2.345			.	0.0116	ns	0.0005	ns	ns	ns
sep x2	4	-2.750	1.708				.	ns	ns	ns	ns	ns
nov x1	2	-0.500	0.707					.	0.0216	ns	ns	ns
nov x2	3	-3.667	2.566						.	ns	0.0059	0.0020
apr x1	2	-1.500	0.707							.	ns	ns
apr x2	6	-2.667	4.457								.	ns
no burn	8	-0.250	1.336									.

Plantago lanceolata log

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	2	-2.250	1.768	.	ns	ns	ns	ns	ns	ns	ns	ns
jun x2	1	-4.000	.		.	ns	ns	ns	ns	ns	ns	ns
sep x1	2	0.250	0.354			.	ns	ns	ns	ns	ns	ns
sep x2	3	-3.500	0.500				.	0.0242	ns	ns	ns	ns
nov x1	3	0.500	1.323					.	0.0324	ns	ns	ns
nov x2	2	-5.250	3.889						.	ns	ns	ns
apr x1	2	-2.000	2.828							.	ns	ns
apr x2	3	-4.000	4.359								.	ns
no burn	5	-1.000	1.581									.

Ptilotus spathulatus none

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	3	0.167	0.289	.	ns	0.0162	0.0486	ns	ns	ns	ns	ns
jun x2	5	0.000	0.354		.	0.0421	ns	ns	0.0421	ns	ns	ns
sep x1	2	-0.500	0.000			.	ns	0.0042	0.0022	ns	ns	0.0162
sep x2	1	-0.500	.				.	0.0172	0.0086	ns	ns	0.0486
nov x1	3	0.333	0.289					.	ns	ns	ns	ns
nov x2	2	0.500	0.000						.	ns	ns	ns
apr x1	3	0.000	0.000							.	ns	ns
apr x2	1	0.000	.								.	ns
no burn	3	0.167	0.289									.

ERECT ROSETTE HEMICRYPTOPHYTES log

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	10	0.600	6.923	.	ns	ns	ns	ns	ns	ns	ns	ns
jun x2	13	-7.346	14.869		.	0.0261	ns	0.0225	ns	ns	ns	ns
sep x1	11	0.727	3.684			.	ns	ns	0.0213	ns	ns	ns
sep x2	13	-7.000	21.184				.	ns	ns	ns	ns	ns
nov x1	9	1.222	4.803					.	0.0185	ns	ns	ns
nov x2	14	-4.571	7.309						.	ns	ns	ns
apr x1	11	0.045	3.698							.	ns	ns
apr x2	14	-3.286	10.362								.	ns
no burn	20	-1.000	4.554									.

Continued next page.

Table 5.9. Continued from above page.

Carex breviculmis none

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	9	-3.333	2.305	.	ns	ns	ns	ns	ns	ns	ns	ns
jun x2	14	-2.250	1.795		.	ns	ns	ns	ns	ns	ns	ns
sep x1	10	-4.250	3.684			.	ns	ns	ns	ns	ns	ns
sep x2	13	-3.269	3.046				.	ns	ns	ns	ns	ns
nov x1	10	-3.000	2.906					.	ns	ns	ns	ns
nov x2	11	-3.273	3.133						.	ns	ns	ns
apr x1	10	-3.600	2.894							.	ns	ns
apr x2	13	-3.115	3.720								.	ns
no burn	20	-3.925	2.988									.

Plantago varia

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	3	-1.167	1.155	.	ns	ns	ns	ns	ns	ns	0.0478	0.0182
jun x2	2	-0.750	0.354		.	ns	ns	ns	ns	ns	ns	ns
sep x1	6	-0.167	0.876			.	ns	ns	ns	ns	ns	ns
sep x2	3	-1.167	0.764				.	ns	ns	ns	0.0478	0.0182
nov x1	6	-0.250	0.418					.	ns	ns	ns	ns
nov x2	2	0.000	0.707						.	ns	ns	ns
apr x1	3	-1.167	0.764							.	0.0478	0.0182
apr x2	2	0.250	1.061								.	ns
no burn	6	0.167	0.606									.

Tragopogon porrifolius none

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	5	0.100	0.652	.	ns	ns	ns	ns	ns	ns	ns	ns
jun x2	1	0.000	.		.	ns	ns	ns	ns	ns	ns	ns
sep x1	5	0.100	0.418			.	ns	ns	ns	ns	ns	ns
sep x2	3	-0.667	1.258				.	ns	ns	ns	ns	ns
nov x1	6	0.250	0.418					.	ns	ns	ns	ns
nov x2	4	0.000	0.707						.	ns	ns	ns
apr x1	4	0.250	0.500							.	ns	ns
apr x2	2	-0.500	1.414								.	ns
no burn	6	0.250	0.274									.

PARTIAL ROSETTE HEMICRYPTOPHYTES none

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	5	-0.600	1.782	.	ns	ns	0.0328	ns	ns	ns	ns	ns
jun x2	5	-2.400	3.305		.	ns	ns	ns	ns	ns	ns	ns
sep x1	5	1.200	2.168			.	0.0041	ns	0.0114	ns	0.0196	ns
sep x2	4	-5.375	2.428				.	0.0178	ns	ns	ns	0.0256
nov x1	4	0.250	1.443					.	0.0459	ns	ns	ns
nov x2	5	-4.200	5.529						.	ns	ns	ns
apr x1	5	-1.500	1.581							.	ns	ns
apr x2	9	-3.167	4.802								.	ns
no burn	9	-0.889	1.616									.

Continued next page.

Table 5.9. Continued from above page.

Acaena echinata log

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	5	0.300	0.447	.	ns	ns	ns	ns	ns	ns	ns	ns
jun x2	8	4.500	10.351		.	ns	ns	ns	ns	ns	ns	ns
sep x1	6	0.667	1.966			.	ns	ns	ns	ns	ns	ns
sep x2	7	0.857	0.556				.	ns	ns	ns	ns	ns
nov x1	4	1.500	1.958					.	ns	ns	ns	ns
nov x2	6	0.500	0.632						.	ns	ns	ns
apr x1	3	0.500	0.000							.	ns	ns
apr x2	7	2.643	3.351								.	ns
no burn	6	2.167	2.961									.

Leptorynchos squamatus log

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	8	-3.625	5.463	.	ns	ns	ns	ns	ns	ns	ns	ns
jun x2	8	-7.438	12.833		.	ns	ns	ns	ns	ns	ns	ns
sep x1	8	-0.938	3.017			.	ns	ns	ns	ns	0.0207	ns
sep x2	6	-1.917	5.044				.	ns	ns	ns	0.0107	ns
nov x1	3	-0.500	0.866					.	ns	ns	ns	ns
nov x2	5	-6.100	7.369						.	ns	ns	ns
apr x1	5	-2.700	3.114							.	ns	ns
apr x2	3	-8.833	9.929								.	ns
no burn	11	-7.182	14.232									.

Chrysocephalum apiculatum log

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	6	0.167	0.408	.	ns	ns	ns	ns	ns	ns	ns	ns
jun x2	9	0.778	1.970		.	0.0291	0.0193	0.0435	ns	ns	ns	0.0428
sep x1	7	-1.000	1.848			.	ns	ns	ns	ns	ns	ns
sep x2	8	-0.938	1.374				.	ns	ns	ns	ns	ns
nov x1	6	-0.583	0.801					.	ns	ns	ns	ns
nov x2	8	0.063	0.496						.	ns	ns	ns
apr x1	8	-0.625	1.598							.	ns	ns
apr x2	8	-0.563	1.860								.	ns
no burn	9	-0.667	1.936									.

Lomandra nana log

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	4	0.250	0.289	.	ns	ns	ns	ns	ns	ns	ns	ns
jun x2	6	0.417	0.376		.	ns	ns	ns	ns	ns	ns	ns
sep x1	4	0.500	0.000			.	ns	ns	0.0217	ns	ns	ns
sep x2	4	0.250	0.289				.	ns	ns	ns	ns	ns
nov x1	5	0.200	0.274					.	ns	ns	ns	ns
nov x2	8	0.125	0.231						.	ns	ns	ns
apr x1	2	0.500	0.000							.	ns	ns
apr x2	2	0.500	0.000								.	ns
no burn	4	0.375	0.250									.

Continued next page.

Table 5.9. Continued from above page.

PROTO-HEMICRYPTOPHYTES sqrt

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	10	-3.150	2.506	.	ns	ns	ns	ns	ns	ns	ns	ns
jun x2	14	0.214	7.982		.	ns	ns	ns	ns	ns	ns	ns
sep x1	11	-3.455	4.401			.	ns	ns	ns	ns	ns	ns
sep x2	13	-3.308	3.106				.	ns	ns	ns	ns	ns
nov x1	10	-2.350	3.056					.	ns	ns	ns	ns
nov x2	13	-2.269	2.603						.	ns	ns	ns
apr x1	11	-3.455	3.387							.	ns	ns
apr x2	13	-1.692	4.451								.	ns
no burn	22	-2.909	3.782									.

Convolvulus erubescens

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	5	-0.300	0.274	.	ns	ns	ns	ns	ns	ns	ns	ns
jun x2	4	-0.875	1.548		.	ns	0.0467	ns	ns	ns	ns	ns
sep x1	1	0.000	.			.	ns	ns	ns	ns	ns	ns
sep x2	4	0.125	0.250				.	ns	ns	ns	ns	ns
nov x1	3	0.000	0.500					.	ns	ns	ns	ns
nov x2	8	-0.313	0.799						.	ns	ns	ns
apr x1	4	0.000	0.577							.	ns	ns
apr x2	5	-0.300	0.570								.	ns
no burn	10	-0.150	0.412									.

Geranium solanderi sqrt

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	3	1.333	0.577	.	ns	ns	ns	0.0097	ns	ns	ns	ns
jun x2	4	0.250	0.645		.	0.0362	ns	0.0001	ns	0.0090	ns	ns
sep x1	4	1.500	1.225			.	ns	0.0078	ns	ns	ns	0.0288
sep x2	4	1.250	0.957				.	0.0040	ns	ns	ns	ns
nov x1	2	6.000	4.243					.	0.0014	0.0157	0.0014	0.0001
nov x2	3	0.667	0.289						.	ns	ns	ns
apr x1	5	2.000	1.969							.	ns	0.0056
apr x2	3	0.667	0.289								.	ns
no burn	6	0.167	0.408									.

Vittadinia cuneata none

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	2	-0.750	0.354	.	ns	ns	ns	ns	ns	ns	ns	ns
jun x2	5	-0.400	0.652		.	ns	ns	ns	ns	ns	ns	ns
sep x1	4	-0.125	0.629			.	ns	ns	ns	ns	ns	ns
sep x2	4	-0.125	0.479				.	ns	ns	ns	ns	ns
nov x1	3	0.167	0.289					.	ns	ns	ns	ns
nov x2	3	-0.500	1.323						.	ns	ns	ns
apr x1	3	0.000	0.000							.	ns	ns
apr x2	4	-0.500	0.707								.	ns
no burn	5	-0.100	0.418									.

Vittadinia muelleri log

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	6	0.583	0.736	.	0.0173	ns	0.0202	ns	0.0099	ns	ns	0.0403
jun x2	5	-7.800	11.128		.	ns	ns	ns	ns	ns	ns	ns
sep x1	3	0.167	1.443			.	ns	ns	ns	ns	ns	ns
sep x2	6	-5.167	7.834				.	ns	ns	ns	ns	ns
nov x1	3	-1.000	3.606					.	ns	ns	ns	ns
nov x2	7	-5.071	5.719						.	ns	ns	ns
apr x1	7	0.000	1.472							.	ns	ns
apr x2	7	-5.000	9.958								.	ns
no burn	9	-2.500	3.428									.

CAESPITOSE HEMICRYPTOPHYTES

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	10	6.100	13.197	.	ns	ns	ns	ns	0.0140	0.0251	0.0026	ns
jun x2	14	-4.500	15.540		.	ns	ns	ns	ns	ns	ns	ns
sep x1	11	2.727	15.381			.	ns	ns	0.0472	ns	0.0104	ns
sep x2	14	-2.286	12.496				.	ns	ns	ns	ns	ns
nov x1	10	-2.650	18.043					.	ns	ns	ns	ns
nov x2	14	-9.357	14.193						.	ns	ns	0.0209
apr x1	11	-8.727	15.252							.	ns	0.0423
apr x2	14	-12.964	14.954								.	0.0029
no burn	22	2.614	15.299									.

Danthonia spp.

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	1	1.500	.	.	ns	ns	0.0083	ns	ns	ns	0.0435	ns
jun x2	6	0.250	0.418		.	ns	0.0131	ns	ns	ns	ns	ns
sep x1	4	0.375	0.250			.	0.0145	ns	ns	ns	ns	ns
sep x2	6	-1.000	1.449				.	0.0055	0.0349	0.0222	ns	0.0328
nov x1	2	1.000	1.414					.	ns	ns	ns	ns
nov x2	5	0.100	0.418						.	ns	ns	ns
apr x1	5	0.200	0.570							.	ns	ns
apr x2	5	-0.400	0.894								.	ns
no burn	10	-0.050	0.762									.

Elymus scaber log

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	5	-1.700	3.667	.	ns	ns	ns	ns	ns	ns	ns	ns
jun x2	6	-3.917	3.747		.	ns	ns	ns	ns	ns	ns	ns
sep x1	6	-3.500	4.775			.	ns	ns	ns	ns	ns	ns
sep x2	7	-1.000	4.163				.	ns	ns	ns	ns	ns
nov x1	5	-3.100	3.782					.	ns	ns	ns	ns
nov x2	8	-1.688	1.413						.	ns	ns	ns
apr x1	7	-1.857	2.897							.	ns	ns
apr x2	6	-3.417	2.616								.	ns
no burn	6	-5.000	12.763									.

Continued next page.

Table 5.9. Continued from above page.

Lolium perenne log

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	4	-0.875	5.391	.	ns	ns	ns	ns	ns	ns	ns	ns
jun x2	4	-1.750	2.217		.	ns	ns	ns	ns	ns	ns	ns
sep x1	4	-1.000	4.082			.	ns	ns	ns	ns	ns	ns
sep x2	7	-0.500	0.707				.	ns	ns	ns	ns	ns
nov x1	2	-1.750	3.182					.	ns	ns	ns	ns
nov x2	7	-4.357	6.625						.	ns	ns	0.0073
apr x1	3	-3.667	2.843							.	ns	ns
apr x2	5	-3.600	5.617								.	ns
no burn	9	0.333	2.046									.

Poa bulbosa log

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	4	3.750	4.975	.	ns	ns	ns	ns	ns	ns	ns	ns
jun x2	6	-7.583	20.480		.	ns	ns	ns	ns	ns	ns	ns
sep x1	4	2.250	3.175			.	ns	ns	ns	ns	ns	ns
sep x2	4	-13.500	38.803				.	ns	ns	ns	ns	ns
nov x1	2	0.500	0.000					.	ns	ns	ns	ns
nov x2	4	0.625	3.198						.	ns	ns	ns
apr x1	3	1.000	0.866							.	ns	ns
apr x2	5	2.200	9.859								.	ns
no burn	5	0.800	8.962									.

Poa pratensis

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	7	-6.714	12.271	.	ns	ns	ns	ns	ns	ns	ns	ns
jun x2	8	-1.313	5.291		.	ns	ns	ns	ns	ns	ns	ns
sep x1	7	-6.571	6.754			.	ns	ns	ns	ns	ns	ns
sep x2	10	-3.950	8.428				.	ns	ns	ns	ns	ns
nov x1	8	-4.688	6.285					.	ns	ns	ns	ns
nov x2	11	-0.909	4.409						.	ns	ns	ns
apr x1	8	-2.250	5.445							.	ns	ns
apr x2	9	-6.944	8.297								.	ns
no burn	16	-2.781	5.298									.

Schoenus absconditis log

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	7	7.643	12.257	.	ns	ns	ns	ns	ns	ns	ns	ns
jun x2	10	0.550	1.739		.	ns	ns	ns	ns	ns	ns	ns
sep x1	9	5.111	6.533			.	ns	ns	0.0415	ns	ns	ns
sep x2	11	2.136	3.155				.	ns	ns	ns	ns	ns
nov x1	7	5.214	14.106					.	ns	ns	ns	ns
nov x2	10	0.100	2.145						.	ns	ns	ns
apr x1	7	0.143	5.154							.	ns	ns
apr x2	11	0.455	0.723								.	ns
no burn	17	2.882	5.667									.

Continued next page.

Table 5.9. Continued from above page.

Stipa spp. log

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	7	-0.857	7.603	.	ns	ns	ns	ns	0.0451	ns	ns	ns
jun x2	11	-1.227	5.493		.	ns	ns	ns	ns	ns	ns	ns
sep x1	8	-2.938	10.510			.	ns	ns	ns	ns	ns	ns
sep x2	12	-2.500	5.187				.	ns	ns	ns	ns	ns
nov x1	5	-3.700	6.723					.	ns	ns	ns	ns
nov x2	12	-4.167	6.750						.	ns	ns	0.0086
apr x1	7	-4.071	6.031							.	ns	ns
apr x2	9	-2.111	3.863								.	0.0445
no burn	17	0.676	5.309									.

Themeda triandra none

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	8	8.500	13.774	.	ns	ns	ns	ns	ns	ns	0.0245	ns
jun x2	12	-0.542	14.917		.	ns	ns	ns	ns	ns	ns	ns
sep x1	9	9.500	11.581			.	ns	ns	ns	0.0448	0.0133	ns
sep x2	10	4.500	8.708				.	ns	ns	ns	ns	ns
nov x1	7	1.143	21.412					.	ns	ns	ns	ns
nov x2	11	-2.091	8.467						.	ns	ns	ns
apr x1	9	-3.667	14.491							.	ns	ns
apr x2	11	-6.091	16.140								.	ns
no burn	18	4.222	13.059									.

EXOTIC ABUNDANCE

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	10	-8.450	8.814	.	ns	ns	ns	ns	ns	ns	ns	ns
jun x2	14	-16.857	15.829		.	ns	ns	ns	ns	ns	ns	ns
sep x1	11	-10.409	9.205			.	ns	ns	ns	ns	ns	ns
sep x2	14	-14.850	22.720				.	ns	ns	ns	ns	ns
nov x1	10	-9.450	8.678					.	ns	ns	ns	ns
nov x2	14	-12.679	19.644						.	ns	ns	ns
apr x1	11	-5.182	8.091							.	ns	ns
apr x2	14	-12.250	19.567								.	ns
no burn	22	-8.250	15.763									.

EXOTIC GRASS

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	10	-3.950	10.500	.	ns	ns	ns	ns	ns	ns	ns	ns
jun x2	14	-7.429	11.087		.	ns	ns	ns	ns	ns	ns	ns
sep x1	11	-9.318	12.452			.	ns	ns	ns	ns	ns	ns
sep x2	14	-6.964	10.842				.	ns	ns	ns	ns	ns
nov x1	10	-5.350	5.682					.	ns	ns	ns	ns
nov x2	14	-6.036	11.836						.	ns	ns	ns
apr x1	11	-1.545	5.303							.	ns	ns
apr x2	14	-4.071	8.797								.	ns
no burn	22	-3.886	11.430									.

Continued next page.

Table 5.9. Continued from above page.

EXOTIC FORB

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	10	-8.500	9.513	.	ns	ns	ns	ns	ns	ns	ns	ns
jun x2	14	-11.714	13.779		.	ns	ns	ns	ns	ns	ns	ns
sep x1	11	-4.864	9.309			.	ns	ns	ns	ns	ns	ns
sep x2	14	-7.071	16.273				.	ns	ns	ns	ns	ns
nov x1	10	-5.850	8.052					.	ns	ns	ns	ns
nov x2	14	-11.429	13.180						.	ns	ns	ns
apr x1	11	-6.591	6.956							.	ns	ns
apr x2	14	-9.464	13.810								.	ns
no burn	22	-6.955	12.051									.

NATIVE ABUNDANCE

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	10	4.800	21.461	.	ns	ns	ns	ns	0.0031	0.0164	0.0065	ns
jun x2	14	-5.643	15.188		.	ns	ns	ns	ns	ns	ns	ns
sep x1	11	4.364	18.558			.	ns	ns	0.0029	0.0164	0.0062	ns
sep x2	14	-5.786	15.926				.	ns	ns	ns	ns	ns
nov x1	10	-1.100	24.141					.	0.0294	ns	ns	ns
nov x2	14	-16.964	12.733						.	ns	ns	0.0064
apr x1	11	-13.682	20.217							.	ns	0.0414
apr x2	14	-15.143	15.491								.	0.0148
no burn	22	-0.455	15.446									.

NATIVE GRASS

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	10	10.800	17.466	.	0.0340	ns	ns	ns	0.0012	0.0224	0.0096	ns
jun x2	14	-3.000	14.697		.	ns	ns	ns	ns	ns	ns	ns
sep x1	11	8.273	15.634			.	ns	ns	0.0032	0.0489	0.0231	ns
sep x2	14	0.571	10.021				.	ns	ns	ns	ns	ns
nov x1	10	3.800	23.127					.	0.0274	ns	ns	ns
nov x2	14	-10.571	14.319						.	ns	ns	0.0032
apr x1	11	-4.909	18.452							.	ns	ns
apr x2	14	-6.143	12.624								.	0.0316
no burn	22	5.409	14.634									.

NATIVE FORB

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	10	-4.900	6.204	.	ns	ns	ns	ns	ns	ns	ns	ns
jun x2	14	-0.786	10.691		.	ns	0.0187	ns	0.0442	ns	ns	ns
sep x1	11	-4.273	4.730			.	ns	ns	ns	ns	ns	ns
sep x2	14	-8.071	8.737				.	ns	ns	ns	ns	ns
nov x1	10	-6.200	5.448					.	ns	ns	ns	ns
nov x2	14	-7.000	6.912						.	ns	ns	ns
apr x1	11	-6.273	9.368							.	ns	ns
apr x2	14	-6.071	8.794								.	ns
no burn	22	-5.864	8.228									.

Continued next page.

Table 5.9. Continued from above page.

RICHNESS

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	10	3.700	3.268	.	0.0325	ns	0.0415	ns	ns	ns	ns	ns
jun x2	14	0.714	2.644		.	ns	ns	ns	ns	ns	ns	ns
sep x1	11	3.182	2.714			.	ns	ns	ns	ns	ns	ns
sep x2	14	0.857	3.697				.	ns	ns	ns	ns	ns
nov x1	10	3.100	3.446					.	ns	ns	ns	ns
nov x2	14	1.071	3.689						.	ns	ns	ns
apr x1	11	3.273	3.101							.	ns	ns
apr x2	14	2.071	4.028								.	ns
no burn	22	1.591	3.096									.

NATIVE RICHNESS

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	10	1.300	2.111	.	ns	ns	ns	ns	ns	ns	ns	ns
jun x2	14	0.857	1.027		.	ns	ns	ns	ns	ns	ns	ns
sep x1	11	2.000	2.191			.	ns	ns	ns	ns	ns	ns
sep x2	14	0.714	1.490				.	ns	ns	ns	ns	ns
nov x1	10	1.200	2.394					.	ns	ns	ns	ns
nov x2	14	0.714	2.091						.	ns	ns	ns
apr x1	11	1.818	2.272							.	ns	ns
apr x2	14	1.571	2.901								.	ns
no burn	22	0.500	1.921									.

EXOTIC RICHNESS

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	10	2.400	2.459	.	0.0153	ns	0.0308	ns	ns	ns	ns	ns
jun x2	14	-0.143	2.143		.	ns	ns	ns	ns	ns	ns	ns
sep x1	11	1.182	1.834			.	ns	ns	ns	ns	ns	ns
sep x2	14	0.143	2.770				.	ns	ns	ns	ns	ns
nov x1	10	1.900	2.726					.	ns	ns	ns	ns
nov x2	14	0.357	3.079						.	ns	ns	ns
apr x1	11	1.455	2.382							.	ns	ns
apr x2	14	0.500	2.504								.	ns
no burn	22	1.091	2.328									.

TOTAL PLANT COVER

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	10	-3.650	19.619	.	0.0241	ns	0.0422	ns	0.0021	ns	0.0048	ns
jun x2	14	-22.500	15.117		.	0.0426	ns	ns	ns	ns	ns	0.0451
sep x1	11	-6.045	19.257			.	ns	ns	0.0040	ns	0.0090	ns
sep x2	14	-20.600	26.293				.	ns	ns	ns	ns	ns
nov x1	10	-10.550	19.836					.	0.0224	ns	0.0434	ns
nov x2	14	-29.643	18.588						.	ns	ns	0.0026
apr x1	11	-18.864	17.709							.	ns	ns
apr x2	14	-27.393	19.892								.	0.0071
no burn	22	-8.705	20.208									.

Continued next page.

Table 5.9. Continued from above page.

BARE GROUND

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	10	12.000	26.051	.	ns	ns	0.0180	ns	0.0004	ns	ns	ns
jun x2	14	18.857	17.654		.	ns	ns	ns	0.0026	ns	ns	0.0052
sep x1	11	12.727	24.483			.	0.0191	ns	0.0004	ns	ns	ns
sep x2	14	31.929	18.606				.	ns	ns	ns	ns	0.0001
nov x1	10	20.600	24.618					.	0.0106	ns	ns	0.0063
nov x2	14	42.179	25.073						.	0.0306	ns	0.0001
apr x1	11	24.500	22.456							.	ns	0.0009
apr x2	14	27.214	13.348								.	0.0001
no burn	22	-0.682	11.814									.

LITTER

season	N	Mean	SD	jun x1	jun x2	sep x1	sep x2	nov x1	nov x2	apr x1	apr x2	no burn
jun x1	10	9.350	15.492	.	ns	ns	ns	ns	ns	ns	ns	ns
jun x2	14	4.036	13.152		.	ns	ns	ns	ns	ns	ns	0.0156
sep x1	11	11.273	15.623			.	ns	ns	ns	ns	ns	ns
sep x2	14	0.536	21.195				.	ns	ns	ns	ns	0.0023
nov x1	10	2.950	10.555					.	ns	ns	ns	0.0188
nov x2	14	1.893	18.617						.	ns	ns	0.0051
apr x1	11	3.591	7.053							.	ns	0.0204
apr x2	14	4.964	11.704								.	0.0244
no burn	22	17.091	17.378									.

Table 5.10 Table of responses to burning of taxa, life<*form groups, major taxonomic groups, and native and exotic species richness and site variables. The probability of changes being different and the direction of different are given. Differences are determined by comparison of LS means of changes in cover between June 1992 and December 1994. < indicates that taxa is less following first category compared second category. > indicates that taxa is greater following first category compared second category. * P<0.05, ** P<0.01, ***P<0.001

	jun x1 vs apr x1	sep x1 vs apr x1	nov x1 vs apr x1	jun x1 vs no burn	sep x1 vs no burn	nov x1 vs no burn	apr x1 vs no burn	jun x2 vs apr x2	sep x2 vs apr x2	nov x2 vs apr x2	jun x2 vs no burn	sep x2 vs no burn	nov x2 vs no burn	apr x2 vs no burn
THEROPHYTES	ns	<*	ns	ns	<**	ns	ns	ns	ns	ns	<*	ns	<*	ns
Aira caryophyllea	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Briza minor	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Bromus hordeaceus	ns	ns	ns	<**	<***	<**	<*	ns	ns	ns	<**	<*	<**	<**
Centaurium erythraea	ns	ns	ns	ns	<*	<***	ns	ns	>*	ns	<**	ns	<***	<***
Cirsium vulgare	ns	ns	ns	ns	ns	ns	ns	ns	>*	ns	ns	>*	ns	ns
Cynosurus echinatus	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	<*	ns	ns	ns
Trifolium dubium	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Trifolium striatum	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	>*	ns	ns	ns
Trifolium subterraneum	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Vulpia spp.	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CHAMAEPHYTES	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Asperula conferta	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
FLAT/VERS ROSETTE HEMIS	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Hypochoeris radicata	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Oxalis perennans	ns	ns	ns	ns	ns	ns	ns	ns	ns	<**	ns	ns	<**	ns
Plantago lanceolata	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Ptilotus spathulatus	ns	ns	ns	ns	<*	ns	ns	ns	ns	ns	ns	<*	ns	ns

Table continued next page

Table 5.10. Continued from above page

	jun x1 vs apr x1	sep x1 vs apr x1	nov x1 vs apr x1	jun x1 vs no burn	sep x1 vs no burn	nov x1 vs no burn	apr x1 vs no burn	jun x2 vs apr x2	sep x2 vs apr x2	nov x2 vs apr x2	jun x2 vs no burn	sep x2 vs no burn	nov x2 vs no burn	apr x2 vs no burn
ERECT ROSETTE HEMIS	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Carex breviculmis	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Plantago varia	ns	ns	ns	<*	ns	ns	<*	ns	<*	ns	ns	<*	ns	ns
Tragopogon porrifolius	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
PARTIAL ROSETTE HEMIS	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Acaena echinata	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Leptorynchos squamatus	ns	ns	ns	ns	ns	ns	ns	ns	>*	ns	ns	ns	ns	ns
Chrysocephalum apiculatum	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	>*	ns	ns	ns
Lomandra nana	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
PROTO-HEMIS	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Convolvulus erubescens	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Geranium solanderi	ns	ns	>*	ns	>*	>***	>**	ns	ns	ns	ns	ns	ns	ns
Vittadinia cuneata	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Vittadinia muelleri	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CAESPITOSE HEMIS	>*	ns	ns	ns	ns	ns	<*	ns	ns	ns	ns	ns	<*	<**
Danthonia spp.	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	<*	ns	ns
Elymus scaber	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Lolium perenne	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	<**	ns
Poa bulbosa	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Poa pratensis	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Schoenus absconditis	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Stipa spp.	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	<**	<*
Themeda triandra	ns	>*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

Table continued next page

Table 5.10. Continued from above page

	jun x1 vs apr x1	sep x1 vs apr x1	nov x1 vs apr x1	jun x1 vs no burn	sep x1 vs no burn	nov x1 vs no burn	apr x1 vs no burn	jun x2 vs apr x2	sep x2 vs apr x2	nov x2 vs apr x2	jun x2 vs no burn	sep x2 vs no burn	nov x2 vs no burn	apr x2 vs no burn
EXOTIC ABUNDANCE	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
EXOTIC GRASS	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
EXOTIC FORB	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
NATIVE ABUNDANCE	>*	>*	ns	ns	ns	ns	<*	ns	ns	ns	ns	ns	<**	<*
NATIVE GRASS	>*	>*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	<**	<*
NATIVE FORB	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
RICHNESS	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
NATIVE RICHNESS	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
EXOTIC RICHNESS	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
TOTAL PLANT COVER	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	<*	ns	<**	<**
BARE GROUND	ns	ns	ns	ns	ns	>**	>***	ns	ns	ns	>**	>***	>***	>***
LITTER	ns	ns	ns	ns	ns	<*	<*	ns	ns	ns	<*	<**	<**	<*

GLMs were significant for 12 of the 53 species, life-form groups and site variables (Table 5.6). Effects of the number of burns and the differences seasons overall were significant for 15 and 4 respectively out of the 53 species, life-form groups and site variables (Table 5.6).

There were a small number of species, life-form groups and site variables which were significantly different following the different burning treatments (Table 5.6). This was partly due to the large variation in the changes which generally occurred between the plots with the same treatments (Table 5.9). The variability in the results may have been due to the variability in the original vegetation in the plots.

The only two life-form groups in which changes in cover were significantly different following any of the different burning treatments were therophytes and caespitose hemicryptophytes (Table 5.10).

Therophytes were significantly less following the single September burn compared to both the single April burn and the no burn treatment, and were significant less following both the June and November consecutive burns compared to the no burn treatment (Table 5.9). There were no significant differences following the April burn treatment. This indicates that there is a depressive effect on the cover of therophytes following winter and spring burn treatments.

There were a number of individual therophyte species which were less following burns compared to the no burn treatment. *Bromus hordeaceus* was less abundant following all the burning treatments compared to the no burn treatment. The levels of significance of the decreases following the double-burning treatments were not greater than following single burns, and therefore it can not be determined whether the double burning treatments have had greater effects than the first burn.

Other annual species which are significantly less abundant following burns in winter, early or late spring included *Centaurium erythraea*, which was less abundant following both the single September and November burns compared to the no burn treatment. The cover of *Cirsium vulgare* was significantly lower following the two consecutive September burns compared to both the April burning treatment and the no burn

treatment and *Trifolium striatum* was less abundant following the two June burns compared to the no burn treatment (Table 5.10).

The cover of the caespitose hemicryptophyte life-form group, native grass and native abundance, and *Stipa* spp. were higher following the single June burn compared to the no burn treatment (Table 5.10). *Themeda triandra* was not significantly more abundant, however its mean cover was 4% higher following the June burning treatment compared to the no burn treatment (Table 5.9).

The cover of *T. triandra* and native grasses were higher following the single September burning treatment than the no burn treatment (Table 5.10). There appears to be a promotory effect of the single June and September burning treatments compared to the no burn treatment.

Caespitose hemicryptophytes are significant less following the single April burning treatment. The lack of significant lower cover following either of the 2 x June or the 2 x September burning treatments indicates that the April burning treatment had a negative effect on caespitose hemicryptophytes. The lower mean cover of *Themeda triandra* following the April burn (Table 5.9), again contributed to this trend.

Apart from therophytes and caespitose hemicryptophytes, there were no significant differences between any of the other life-form groups, exotic grasses, exotic forbs or native forbs compared to the no burn treatment. Therefore there appear to be no other trends. However, there were significant differences in the cover of individual species, in addition to the therophytes, following burning treatments compared to the no burn treatment.

The significant differences were mostly with native species and were mostly decreases that followed burning in winter or spring. *Oxalis perennans* was significantly less abundant following the two November burns compared to the no burn treatment and the April burning treatment (Table 5.10). *Ptilotus spathulatus* was significantly less abundant following both the single and double September burns compared to the no burn treatment.

The cover of *Plantago varia* was lower than the no burn treatment following the single June and April and the double September burning treatments. This species appears to be affected by burning independently of the season.

Geranium solanderi had higher cover following single September, November and April burning treatments compared to the no burn treatment and it appears to be promoted by a single burn.

5.4 Discussion

5.4.1 Response of species and life-form groups to burning

Species of therophytes and hemicryptophytes had different responses to the different seasons of burning. Within the therophyte life-form group, there appeared to be a trend for species to have similar responses to the seasons of burning. The trend of responses was the same as the overall life-form group responses. For example, therophytes, and the component species *Centaurium erythraea*, *Cirsium vulgare* and *Trifolium striatum,* all had significantly lower cover following either winter or early or late spring burns compared to the no burn treatment, but were not less following the April burning treatment.

As the growth phase was from before early winter to at least late spring, the populations of therophytes would be expected to be adversely affected by burning in June, September and November, as is the case in this study. The germination following burning would depend on the amounts of seed which did not germinate before the burn. The proportion of seed which germinated in any one year would vary between species.

McDougall (1989*b*), found that *Briza maxima*, a serious exotic annual weedy grass in *Themeda triandra* grassland, was not reduced by burning in spring as persistent soil-stored seed was able to germinate in the following season. As the existence of a large amount of persistent viable soil stored seed is a characteristic of many colonising weedy species, it is likely that there will be some therophytes that will not be eradicated by any single winter or spring burn. Repeated burns would be necessary to exhaust the soil-stored seed bank.

The species of the hemicryptophyte life-form group appeared to have a consistency of response to burning. Apart from the caespitose hemicryptophyte subclass, none of the cover values of the subclasses of hemicryptophyte were significantly different compared to the no burn treatment. Therefore, the classification of species to the level of hemicryptophyte subclass and analysis at that level did not provide any more information than analysis at the higher level of all hemicryptophytes.

The consistent lack of differences in cover following the different treatments indicates that the hemicryptophytes were able to regenerate cover following burning regardless of the season. Groves (1989) observed that exotic tap-rooted species are not reduced by burning. The ability of perennial tap-rooted species to resprout following fire and generate cover, provided there was adequate rainfall, was also noted by Christensen and Burrows (1986). In addition, the deep root systems of some species allows access to deeper soil moisture, which is an advantage as the barer soils following fire are drier (Christensen and Burrows 1986).

The different response of the caespitose hemicryptophyte subclasses appeared to be mainly the result of different responses for *Themeda triandra*. The lower cover of *Themeda triandra* following the single April burning treatment compared to the September burning treatment probably also contributed to the lower levels of native grass and native abundance following single June and September compared to April burning treatments. The different response to different seasons of burning is probably due to its different physiology and is not a consistent life-form group response. The decrease of *Themeda triandra* following November burns appears to be due to the disturbance in its main growing season, that is in late spring and summer.

Themeda triandra is known not to tolerate defoliation in its growing season (Danckwerts and Nel 1989). As well as growth in its most favourable season being disrupted, actively growing plants are apparently more susceptible to fire than dormant plants (Trollope 1984). Lodge and Whalley (1985), were able to selectively reduce *Aristida ramosa,* another warm-season C_4 grass, by adjusting heavy grazing periods to coincide with its main growth. As early spring burning precedes the main growth of *Themeda triandra* it is recommended for the promotion of the growth of *Themeda triandra* in Australian grasslands (Stuwe 1986).

The varying responses of species, in the absence of a trend at the life-form group level, are best examined in relation to characteristics of the individual species. For example, the higher abundance of *Geranium solanderi* following the single September, November and April burning treatments, is related to its rapid regeneration from a strong tap root and the wide spread of leaves which develop. *Geranium solanderi* also responds to summer rainfall with similar fast abundant growth.

There did not appear to be any greater effects following two burns in consecutive years in the same season than single burns. However, comparison of 1 and 2 burns was based on unequal intervals between burning and sampling, for instance, 20 months following the second June burn and only 7 months following the second April burn. The differences in elapsed time before sampling make interpretation difficult.

There were lower cover values of some *Danthonia* spp. *Lolium perenne* and *Stipa* spp. following some of the double burns, however, the lower values may have been due to them not having sufficient time to regrow.

Therophytes may be expected to be disadvantaged to a greater extent following two burns, however this was not seen. However, if perennial species are able to resprout following fire and rapidly regenerate cover it is unlikely that an effect would occur following a second burn.

The importance of the seasonality of burning suggested in the results of this thesis, is consistent with studies in other areas. In contrast, McDougall (1989*a*), found that the time of burning did not have large effects on the species composition of *Themeda triandra* dominated grassland, although he did suggest that after 2 – 3 years of burning in particular season significant differences could occur. Burning in spring promoted *Themeda triandra* and reduced exotic species.

There were increased negative effects of burning on therophytes following the second burn in the same season. The cover values recorded in December 1994, 20 months after the second June burn and 8 months after the second April burn, indicate the year's full recruitment. For other perennial species, the time for growth would need to be considered in interpretation of cover 20 and 8 months after a burn.

5.4.2 The relative importance of germination and resprouting

The lower proportion of regeneration of perennial species from seedlings in this study is a similar finding to what was observed in Victorian grasslands (Lunt 1990), and North American prairies (Glenn-Lewin *et al.* 1990).

In the present study and in the others (Glenn-Lewin *et al.* 1990, Lunt 1990), regeneration of perennials was minor compared to vegetative reproduction. For example, in a *Themeda triandra* grassland, all perennial species resprouted, but only 10 native and 4 exotic perennial species regenerated by seedlings following a burn (Lunt 1990).

Seedlings of some of the native perennial species were recorded in the unburned quadrats but in low numbers. More seedlings of perennial were seen in the burned quadrats.

Following fire, regeneration from seed appears to be common in annual and biennial species, but small numbers of seedlings of perennial species are found (Glenn-Lewin *et al.* 1990). Overall regeneration by seed contributes less to cover than vegetative reproduction (Lunt 1990).

Conversely, germination of perennial species following burning is probably important for many species as successful establishment would be more likely following favorably timed burns followed by good rainfall. Conditions of reduced competition, bare ground, moisture and a flush of nutrients with the deposition of a bed of ash would be ideal for the establishment of seedlings.

In the studies by Lunt (1990), annual species had large numbers of germinants and germination reflected seed bank composition which was dominated by exotic species. He concluded that burning where an exotic seed bank is present is of no benefit to native species richness. However these details are from a single autumn burn. A burn at a less favourable time, such as early spring, may hinder the establishment of exotic annual species.

Exotic seed bank domination is likely to be common in many native grassy communities. However, the abundance of exotic species following burning may occur as a pulse of germination which, over 3 – 5 years, may be of minor importance.

5.4.3 Intensity of burning

Burns are highly variable in characteristics and vegetation patchiness means large variations in fuel load, fuel moisture content, topography and wind speed will occur (Glenn-Lewin *et al.* 1990). Intensities of fires in southeastern Australian grassy communities in spring and autumn will vary according to the vegetation stage, ambient air and soil temperatures, and fuel and soil moisture conditions.

The temperatures of the burns in this study may be unrealistic. Experimental burns in small areas and with external heat sources are likely to be more uniform than a burn on patch fuels (Glenn-Lewin *et al.* 1990). The temperatures of wildfires in grasslands (Norton and Garity 1965, Scotter 1970), were lower than in this study. Although the flame and soil temperatures reached in the experimental burns may be unrealistically high, it does not necessarily follow that the overall effects on the vegetation are dissimilar from a wildfire. The observed levels of combustion of fuels following the experimental burns described in this study are similar to those following planned and unplanned burns in the *Themeda triandra* grassland at TLNR. Resprouting vigour of species did not appear to be different.

Another possible difference is that there may have been greater destruction of seed at or near the soil surface. However, most seed that was buried at a depth of 1 cm or more would probably not be destroyed by soil temperatures in this experiment.

In some seasons the grassy vegetation would not burn. The vegetation dominated by exotic species was green and probably would not burn in winter. The amount of dry fuel tended to be correlated with the amount of native tussock grasses, which provided litter as previous years' dead leaves. *Themeda triandra* provided more fuel than any other grass.

In later spring and summer, when *Themeda triandra* had new green growth, the flammability of the vegetation would depend on the amount of the previous seasons'

growth. The green leaves would not burn. Therefore, the easiest time for fire to burn in exotic grassy vegetation and native grassy vegetation without *Themeda triandra* would be in late spring, summer and autumn, while the easiest time for *Themeda triandra* to burn would be in autumn and winter.

It is suggested that the effects of the experimental burns of this study would be similar to the effects of wildfire in conditions which would produce near complete fuel combustion.

5.4.4 Experimental design

The variability of the vegetation in this experiment reduced the likelihood of obtaining statistically significant differences. Despite this, significant results were obtained for some species. The choice of more uniform vegetation would aid in the detection of trends, however, this would result in less validity in the generalisation of the results to broader areas.

At TLNR the available study area was limited to the approximately 9 ha of grassland excluding boundaries and roads. In such a valuable nature reserve it would not have been appropriate to burn large areas for experimental trials, particularly considering that fire management plans had not yet been developed.

The design of this experiment deliberately kept the burns uniform to determine the response of species to known disturbance, rather than trying to realistically simulate a highly variable event. The determination of whether the results of this study can be applied to another area should be examined in the context of the vegetation and climatic conditions of the other area.

Chapter 6. Restoration of native grassy woodland: weeding techniques and the transplanting of native forbs and grasses

6.1 Introduction

The restoration of native grassy woodland in TLNR involves consideration of the degrees of degradation and alteration of the native plant communities and the goals of restoration, as a basis to choosing the appropriate techniques. TLNR includes areas dominated by exotic grassy vegetation, areas with significant amounts of exotic and native vegetation and areas with small amounts of exotic species in native grassy swards (See Chapter 3).

The goals of restoration of native vegetation where the vegetation is dominated by exotic species would be replacement followed by re-introduction of native species. The aim of this study was to determine the most effective weeding treatments overall, the variation in the effects of the weeding treatments on different exotic species, the success of transplanting nursery reared seedlings into previously weeded areas and the effects on weeding treatments on the survival and flowering of the transplants.

The type of restoration attempt in this study may only be appropriate for areas where near complete alteration of the vegetation has occurred. In areas with partial replacement of the native vegetation the manipulation of the vegetation with less destructive techniques such as fire (Chapter 5) may be more appropriate.

6.1.1 Weed-control techniques

Techniques for the reduction or elimination of weed species before planting and seeding include herbiciding, burning and mechanical treatments such as cultivation and removal of topsoil (scalping).

Herbicides include knockdown herbicides (which kill some or all plants at the time of application) and residual herbicides, (the herbicide continues to act for a time in the soil killing new seedlings). Both knockdown and residual herbicides may be selective or

non-selective. Herbiciding of thick vegetation creates a mulch cover that reduces loss of moisture.

Knockdown herbicides include the non-residual and non-selective herbicide glyphosphate. The rate of uptake of glyphosphate by the plant is related to the rate of metabolic activity of the plant at the time of herbicide application. Plants that are not growing quickly at the time of herbiciding will be less affected. Pre-emergent or residual herbicides include dicamba and MCPA which are selective herbicides that are active against broadleaf plants but not lethal to grasses and clovers, and which are residual for up to 8 months in soil.

Burning as a weed-control technique can be an efficient and cheap method of defoliation and litter removal, provided there are favourable climatic and fuel conditions. Burning has been discussed in Section 1.10 and Chapter 5.

Removal of the top 3 – 5 cm of soil, referred to here as scalping, reduces the soil seed bank, destroys some of the below-ground plant material, and has been suggested for the lessening of high nutrient loads (Marrs 1985). Scalping also leaves a bare soil surface resulting in greater insolation and evaporation stress, and creating a potential for soil erosion. Other effects are that plant roots become closer to the surface and the conditions of the soil profile are altered.

Most experience with weed-control has been in agricultural systems (Roundy and Call 1988, Leys 1990, Martin and Pannell 1990), although some of the techniques are transferable to native plant communities. There have been guidelines developed for weed-control in native vegetation (Bradley 1981, Buchanan 1989, Robin 1991, Carr *et al.* 1992), however, no known studies have analysed in detail the responses of exotic and native species to weeding treatments in natural or semi-natural contexts.

The choice of the best weed-control technique depends on the vegetation and the site. Integrated methods of control are likely to be most effective (Groves 1989). The application of weed-control techniques involves the understanding of ecological processes, the characteristics of species, morphology, life-history, tolerance of the treatments and regeneration biology.

6.1.2 Research questions

- What are the effects of the different weed-control techniques on life-form groups and individual species?

- How is the success of planting native ground-cover species into previously weeded sites dependent on the effectiveness of weed-control?

This study should lead to more effective use of weed-control techniques, especially where some desirable species are present, and to an evaluation of the effects of competition on newly planted species.

The first part of the experiment consists of the application of the weed-control treatments: scalping, herbiciding and burning; the second part consists of the planting of a number of native forbs and grasses that have been raised in a nursery or divided from tussocks.

Monitoring involved assessment of the cover of species, aggregation of the species cover values into life-form and taxonomic groups, the comparison of the cover before and 10 months after the treatments, and the monitoring of survival and flowering of the planted species in relation to the regeneration of the cover following the weed-control treatments.

6.2 Methods

6.2.1 Experimental design and site location

The study site was within the TLNR, in areas had been used for refuse dumping for many years before 1987, when the old tip site was covered over with earth. These areas had > 60% cover of exotic species. These areas were next to and interspersed among the areas of high conservation value.

A randomised complete block design was used, with 10 blocks containing 12 quadrats of 1 m x 1 m in size with an 0.5 m buffer area between them (Fig. 6.1). The scattered refuse dumping pattern over the reserve and the large overall size of the blocks (4 m x

5.5 m) restricted the areas in which the blocks could be placed. Two of the ten blocks were located at a distance from the other blocks, thereby increasing the likely variation in soil types, moisture conditions and vegetation included in the experiment. The other blocks that were located together were on the main area of the old tip site.

Within each block, the 12 quadrats were randomly allocated in one of the 12 possible combinations of the 3 weed-control treatments and control and the 2 planting treatments and control. The weed-control treatments consisted of a scalping treatment, a herbiciding treatment, and a burning treatment.

The randomised complete block design reduced the likelihood of the heterogeneity of environmental conditions affecting the response of vegetation to the treatments (Pearce 1983). The amount of replication was estimated to provide sufficient degrees of freedom for analysis of variance to overcome large variations in the initial vegetation and responses of species to the treatments.

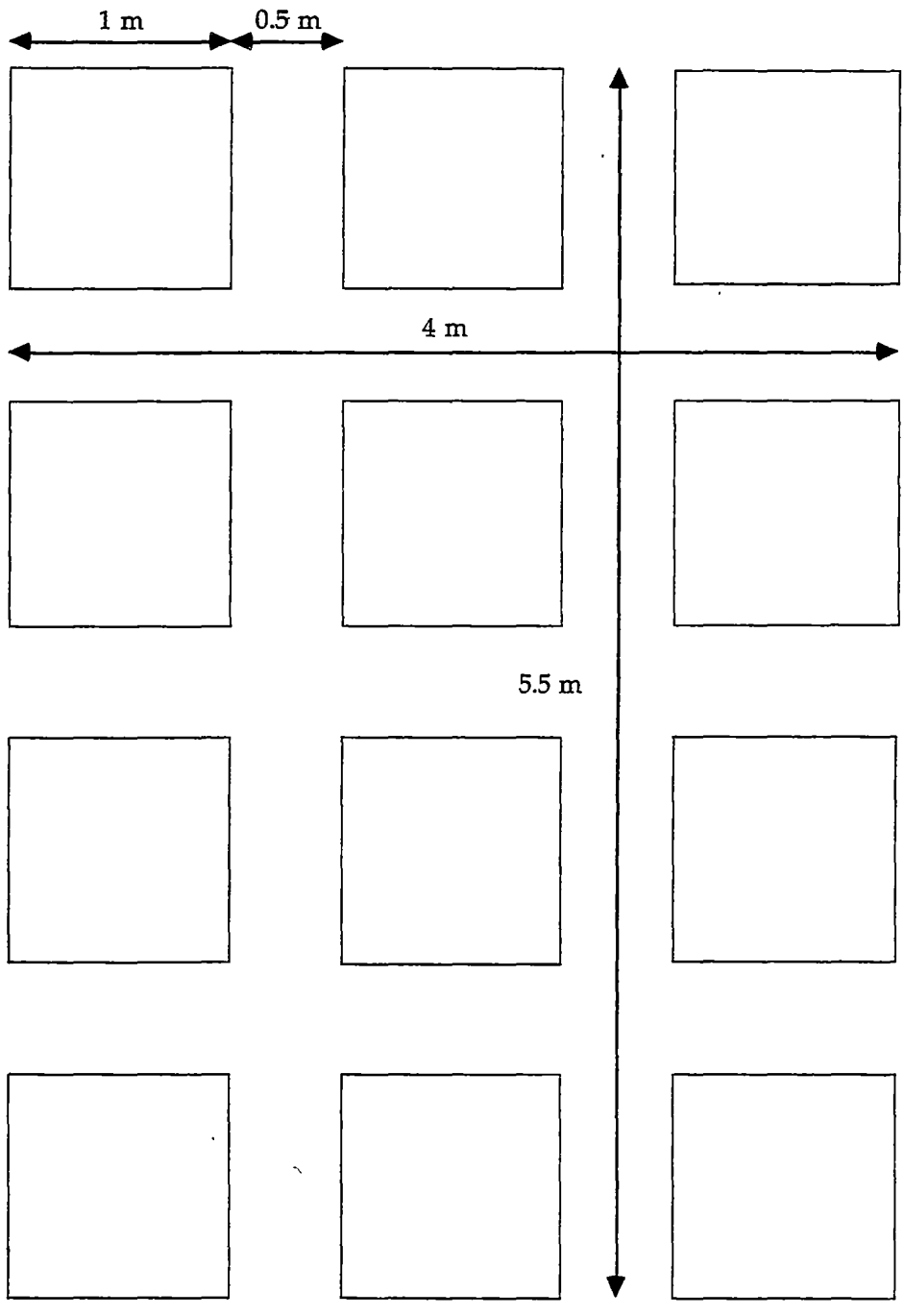

Fig. 6.1. Layout of plots in blocks in weeding and planting experiment

6.2.2 Description of weed-control treatments

The weed-control treatments were methods that could be applied on a broad scale. They were carried out between the 2nd and 6th of September 1991. The scalping treatment consisted of removing the top layer of soil to a depth of 3 – 5 cm using a flat-bladed garden spade pushed in horizontally through the soil, cleanly severing the roots. The top soil was then removed and discarded. Large machinery could be used for a similar effect.

A Hardi K15 backpack sprayer was used to apply a mixture of glyphosphate, dicamba and MCPA active ingredients. Fifteen litres of a mixture of the commercial products, 'Roundup' (6 ml l^{-1} of water) and 'Bindii and Clover Remover' (3 ml l^{-1} of water) was applied to the total area of 30 m^2 in the 30 herbicided quadrats. The effective concentrations of active ingredients were glyphosphate at 1.08 gm^2, MCPA at 0.23 gm^2 and dicamba at 0.04 gm^2.

Spray drift was controlled with a wooden framed box with 1 mm sheet steel lining the inside. The inner dimensions were 1 m x 1 m and 0.2 m high. Very little spray drift occurred, and the spraying was carried out to a stage where all the vegetation was wetted. There was no rain within several days of the spraying date and all plants were dead before planting of the transplants.

A liquid petroleum gas flame (LPG) was passed steadily over the vegetation at a height of approximately 0.2 m. The burning removed all litter and scorched all above ground vegetation and the soil surface. The average time taken was 10 min m^{-2}. However, the thicker, greener swards and thick litter cover of some quadrats required more heating and a longer time.

6.2.3 Planting treatments

The seed of 25 native species was collected between 1985 and 1989 from sites within approximately 20 km of Tunbridge in similar dry lowland grassy habitats to the TLNR. In April 1991, seeds were placed on a germination medium of peat and coarse sand (1 :

1 volume : volume mix) in seedling trays in a glasshouse with an automatic misting system. Of the 25 species, 19 germinated, and of these, 13 germinated in quantities sufficient for this experiment.

Seedlings were pricked out and placed into pots. The potting mix was 1/3 peat, 1/3 sand and 1/3 A1 horizon light clay soil collected from the TLNR in areas of native vegetation adjacent to the refuse site. This soil was used in an attempt to introduce microflora that may assist the growth of the seedlings and to increase the clay content of the mix. The pots varied in size from 50 mm diam and 70 mm depth to 85 mm diam and 150 mm depth. The plants were grown in a glasshouse with a mist watering system until September 1991. The plants were transferred from a glasshouse to a shadehouse with a mild coastal climate and then to an open area near the planting site for further 'hardening' for 2 weeks prior to planting.

The planting treatments consisted of planting a mix of native ground cover species in a regular pattern. The mix of species planted was kept consistent in the different quadrats.

The planting treatments were:

a) planting of 8 nursery-reared seedlings and 8 transplanted tillers of *Themeda triandra*;

b) 8 seedlings and 8 transplants as above plus an individual of *Eucalyptus pauciflora*; and

c) as a control, no individuals were planted.

Holes approximately 50 mm x 50 mm square and 125 mm deep were dug for the seedlings and transplants in a regular pattern. A hand and foot operated tool for digging holes of similar dimensions to the pots, the 'Hamilton Tree Planter', and a slightly larger auger, were used. The plants were placed into the holes and then watered with approximately 250 ml of water. This was the only artificial watering the plants received after planting.

Division of *Themeda triandra* tussocks into tillers was used as an alternative to the planting of nursery-reared transplants due to the lack of germination of *T. triandra* seed. Tussocks were dug from nearby areas. Two to three tillers were divided from the tussocks to be transplanted as a unit. Eighty percent of the tops and the roots of the

tillers were removed and the tillers were then kept in a box until planting. The tillers were exposed to air for on average between 1 and 2 hours and, although the weather was overcast, it was possible that the root hairs were damaged at this time.

The tillers were planted in holes prepared as with the nursery-reared plants. Soil from the holes was replaced into the hole and packed around the roots. Due to the clay texture of the soil it was not possible to pack the soil tightly around the roots of the tillers, and some air spaces remained. Each tiller received approximately 250 ml of water after planting. No fertiliser was added to any of the plots.

6.2.4 Recording of vegetation cover in quadrats

The projective foliage cover values of all quadrats were recorded before planting (August 1991), and on three occasions after planting: after approximately 6 weeks (beginning 31st November), 13 weeks (beginning 18th December) and 9 months (beginning 30th June 1992).

In August 1991, the cover values of all individual species present were assessed by visual estimation of quadrats using a the Braun-Blanquet Cover Abundance Scale (B-B scale) (Mueller-Dombois and Ellenberg 1974). The mid-points of the cover classes were then used in analysis. However, it was considered that the recording of cover using this scale would not be accurate enough to detect changes in cover of species. In June 1992, cover values of species were estimated to the nearest 1%, using a 1 m x 1 m frame with the area divided into 100 units by string at 10 cm intervals in a grid pattern (Mueller-Dombois and Ellenberg 1976). However, as comparison of mid-points of B-B scale cover classes and % cover values could lead to systematic bias in the results, the June 1992 % cover values were then converted to the B-B scale and the mid-points of the cover classes were then used in the analysis.

For some species, identification to species level at that time of year could not be made confidently and the species were aggregated to genus level. These genera included *Stipa*, *Vulpia* and *Trifolium*. Nomenclature follows Buchanan (1995).

The cover of bare ground and litter were recorded. The combined cover of exotic grasses/graminoids, exotic forbs, exotic shrubs, native grasses/graminoids, native forbs, and native shrubs were also recorded. The grass/graminoid and forb classifications are referred to hence as major taxonomic groups and origin refers to whether the species was native or introduced to Tasmania. The cover of the planted individuals of species were excluded from calculation of the cover of pre-existing or regenerating individuals of the species.

In June 1992, the numbers of the different species of plantings surviving and those flowering were recorded.

6.2.5 Analysis procedures

The vegetation and site attribute data for quadrats before and 10 months after the weed-control treatments were entered into the ecological database program DECODA. The species cover data were entered for the August 1991 and the June 1992 recordings separately. The differences in cover before and after was calculated in a spreadsheet program with the absence of a species both before and after recorded as a missing value.

Species were classified according to Raunkiaer life-form classes (Table 2.1), from observation of morphology, phenology and reproductive strategy in the field from 1991 to 1993. Observation included excavation of species suspected to spread vegetatively underground. The total increases or decreases in percentage cover, and the total, exotic and native species richness (alpha-diversity) for the quadrats were determined over the 10 months.

The GLM procedure (SAS 1989) was used to perform a two-way analysis of variance on the differences between before and 10 months after weed-control treatments for untransformed and transformed values of site attributes, cover values of taxa, life-form groups and total, exotic and native species richness. Taxa and life-form groups that were present in less than 40 quadrats were excluded.

The $\log_{10}$ and square root transformations of cover values of species and taxa were calculated using the following equations:

1. logarithmic transformation:

$$\log_{10} (\text{cover of species}) = \log_{10} (\% \text{ cover of species} + 1)$$

2. square root transformation;

$$\text{square root (cover of species)} = \text{square root } (\% \text{ cover of species} + 0.5)$$

Normality of the untransformed and transformed data were tested by plotting standardised residuals and cumulative probability curves as described in McPherson (1990). The transformation was used that both conformed with the tests for normality and resulted in a significant GLM probability. If these requirements were met by the GLM from more than one transformation, the transformation with the most significant GLM was used.

An F test in the GLM procedure (SAS 1989)was used to test for overall significant differences in least squares means between blocks and for weeding and planting treatments and weeding and planting treatment interaction. The transformation or non transformation that both conformed with the above tests for normality and resulted in the F test with the lowest probability was used to examine the changes in cover of species and life-form groups.

In cases where the F test did not indicate significant changes in cover overall it is still possible that there are significant differences in the changes in cover between pairs of treatments. Multiple comparisons of groups that were pre-determined to be of interest were made using unrestricted least significant difference (LSD) or multiple t test as recommended by Saville (1990). The significance of an overall F test is not required for the unrestricted LSD to be determined (Saville 1990).

The total numbers of planted seedlings and transplants surviving and flowering in June 1992, 9 months after planting, were analysed using the GLM procedure as above. The numbers of plantings surviving and flowering were plotted against total plant cover recorded 10 months after planting.

For six of the most common surviving species the individual regression lines of survival plotted against total plant cover were compared using the multiple regression facility in

the REGLIN procedure (SAS 1989). This analysis procedure tested for significantly different responses of the species to total plant cover as recorded in June 1992.

6.3 Results

6.3.1 Effects of weed-control treatments on vegetation

Sixty higher plants species were recorded in the 120 quadrats in August 1991 or in June 1992 (Table 6.1). Thirty-five were introduced, consisting of 8 grass species and 27 forb and shrub species. Twenty-five were native, consisting of 11 forbs and 14 grasses.

There were overall significant differences for 27 of 34 taxa, life-form groups, major taxonomic groups and measures of species richness, plant cover and bare ground (Table 6.1). There were more overall significant differences between blocks (25 of 34), than weeding treatments (19 of 34), and planting treatments (4 of 34) and there were no significant treatment interactions effects (Table 6.1).

Live green plant cover was reduced to zero after all three weed-control treatments. This occurred immediately in the case of scalping and burning, and within approximately 2 – 3 weeks in the herbicided quadrats. None of the weeded quadrats showed visible live shoots at the time of planting.

Scalping resulted in the slowest overall rates of recolonisation (Fig. 6.2). The species that recolonised were the species with buds that were below the scalping blade depth, species with deeply buried seed and species with wind-dispersed seed.

Table 6.1. Number of occurrences of taxa and life-form groups, and the significance of GLM, block effects, weeding and planting treatments and treatment interaction based on the changes in cover from transformation of the mid-points of the Braun-Blanquet Cover Abundance Scale cover classes. Analysis was conduced where N > 24

Species	N	Transform -ation	Signif of GLM	Block effect	Weed treat	Planting treat	Weed x plant treats
Therophytes	120	none	0.0001	0.0001	0.0009	ns	ns
Exotic							
Aphanes arvensis	11						
Brassica rapa	8						
Bromus diandrus	49	Log	0.0362	0.0089	ns	ns	ns
Bromus hordeaceus	26						
Carduus spp.	6						
Centaurium erythraea	7						
Cirsium vulgare	97	Log	0.0116	ns	0.0001	0.0421	ns
Cynosurus echinatus	117	none	0.0001	0.0001	ns	ns	ns
Erodium cicutarium	33						
Silybum marianum	40	none	ns	ns	ns	ns	ns
Sonchus oleraceus	18						
Trifolium spp.	114	none	0.0001	0.0001	0.0001	ns	ns
Vicia sativa	85	log	0.0001	0.0001	ns	0.0247	ns
Vulpia spp.	11						
Chamaephytes	60	log	0.0276	0.0095	ns	ns	ns
Native							
Asperula conferta	59	none	ns	0.0431	ns	ns	ns
Pimelea humilis	3						
Exotic							
Marrubium vulgare	63	log	ns	ns	ns	ns	ns
Flat/vers rosette hemis	120	log	0.0092	0.0107	ns	ns	ns
Native							
Einadia nutans	2						
Oxalis perennans	15						
Ptilotus spathulatus	2						
Rumex dumosus	40	log	0.0024	0.0008	ns	ns	ns
Exotic							
Hypochoeris radicata	96	log	0.0001	0.0025	0.0363	ns	ns
Leontodon taraxacoides	25						
Medicago spp.	39						
Plantago lanceolata	118	none	0.0253	0.0093	ns	ns	ns
Plantago major	4						
Taraxacum officinalis	18						
Erect rosette hemis	120	log	0.0087	0.0118	ns	ns	ns
Native							
Acaena echinata	10						
Carex breviculmis	1						
Dianella revoluta	3						
Pelargonium australe	2						
Plantago varia	28						

Continued next page.

Table 6.1. Continued from above page.

Exotic erect rosette hemis							
Achillea millefloruum	9						
Arrhenatherum elatius	8						
Cardaria draba	28						
Poa pratensis	71	Log	0.0312	0.0153	ns	ns	ns
Tragopogon porrifolius	37						
Partial rosette hemis	49	log	ns	ns	ns	ns	ns
Native							
Chrysocephalum apiculatum	2						
Exotic							
Acetosella vulgaris	8						
Reseda luteola	32						
Rumex spp.	18						
Proto-hemis	106	log	ns	ns	0.0254	ns	ns
Native							
Convolvulus erubescens	14						
Dichondra repens	2						
Geranium solanderi	106	log	ns	ns	0.0181	ns	ns
Vittadinia cuneata	2						
Vittadinia muelleri	7						
Caespitose hemis	120	none	0.0001	0.0121	0.0001	ns	ns
Native							
Danthonia spp.	47	none	ns	ns	ns	ns	ns
Dichelachne spp.	1						
Elymus scaber	60	none	0.0026	0.0207	0.0118	ns	ns
Poa labillardierei	1						
Poa rodwayi	22						
Schoenus absconditis	34						
Stipa spp.	75	log	0.0397	ns	ns	ns	ns
Themeda triandra	60	log	0.0011	0.0008	0.0356	ns	0.0252
Exotic							
Lolium perenne	105	none	0.0001	0.0001	0.0001	ns	ns
Poa bulbosa	14						
Phanerophtyes	12						
Ulex europaeus	12						
Exotic graminoids	120	none	0.0001	0.0001	0.0003	ns	ns
Exotic forb	120	none	0.0001	0.0001	0.0001	ns	ns
Native graminoids	120	none	0.0002	0.0021	0.0005	0.0293	ns
Native forb	120	log	0.0011	ns	0.0050	0.0042	0.0111
Total species richness	120	none	0.0007	0.0001	0.0116	ns	ns
Exotic species richness	120	none	0.0011	0.0002	0.0194	ns	ns
Native species richness	120	none	0.0059	0.0008	0.0333	ns	ns
Plant cover	120	none	0.0001	0.0014	0.0001	ns	ns
Bare Ground	120	none	0.0001	0.0174	0.0001	ns	ns

Plant species which had viable buds remaining below the scalping level were those with deep tap-roots, such as the exotic forbs *Plantago lanceolata* and *Hypochoeris radicata*, those with underground rhizomatous roots, such as *Poa pratensis* and *Asperula conferta*, some larger tussocks, such as *Themeda triandra,* and the bulbs of *Arrhenatherum elatius*. The viable buds resprouted approximately 2 – 4 weeks after scalping.

P. lanceolata was particularly abundant in the scalped quadrats. Scalping revealed a dense rhizomatous mass of *P. pratensis*, which regenerated prolifically. There was also some colonisation from the edges by the rhizomatous species *P. pratensis* and *Asperula conferta.*

Some of the tussocks that were affected by herbiciding eventually resprouted and the effect on underground buds could not be determined directly. Burning scorched all above-ground material except the internal, near ground level buds of tussocks. Green tissue remained in the centre of the rosettes of some larger individuals of *Plantago lanceolata.*

The taxa with the highest cover values in all the quadrats at the end of the trials, *Trifolium* spp., *Plantago lanceolata, Lolium perenne* and *Poa pratensis*, were all exotic species (Fig. 6.2).

Interpretation of differences in cover between before and after weeding treatments

If the change in cover of a taxon of life-form group between before and after a weed-control treatment, was not significantly different from the change in cover of the control, then the taxon of life-form group was regarded as not having been decreased by the weed-control treatment. This was taken to indicate that regeneration of cover occurred and that, after the 10 months, the weed-control treatment did not have a strong negative effect on the cover of the species.

If the change in cover of a taxon or life-form group between before and after a weed-control treatment was a significant decrease compared to the change in cover of the control, then the taxon or life-form group was regarded as having been decreased

following the weed-control treatment. This was taken to indicate slow regrowth or suppression of the taxon or life-form group.

If the change in cover of a taxon or life-form group between before and after a weed-control treatment was a significant increase compared to the change in cover of the control, then the taxon or life-form group was regarded as having been increased by the weed-control treatment. This was taken to indicate rapid regeneration.

Differences in the cover of species and life-form groups following the treatments

There were large amounts of variation, in the control quadrats, of the cover of some species between the first and final recordings. The variations were probably due to seasonal differences between initial and final recordings. Compared to the control, total plant cover was lowest following scalping . Total plant cover was lower following herbiciding and burning compared to the control were not significantly different from eachother (Table 6.2). Total cover abundance of the plantings was up to 5%.

The cover of the therophyte life-form group was lower following scalping, burning and herbiciding treatments compared to the control (Table 6.2). However, the differences in cover of therophytes compared to the control were seen with only some of the species in this group.

Trifolium spp. was significantly less abundant following scalping and burning compared to the control but not with herbiciding compared to the control (Table 6.2). The large difference between cover of *Trifolium* spp. is due to the different seasons of the recordings.

The cover values of *Cirsium vulgare* were highest following herbiciding, next highest following scalping and least highest following burning. All treatments resulted in cover significantly higher than the control. The dead plant material of the herbicided quadrats provided a mulch on the soil surface and soils were noticeably more moist than bare soils.

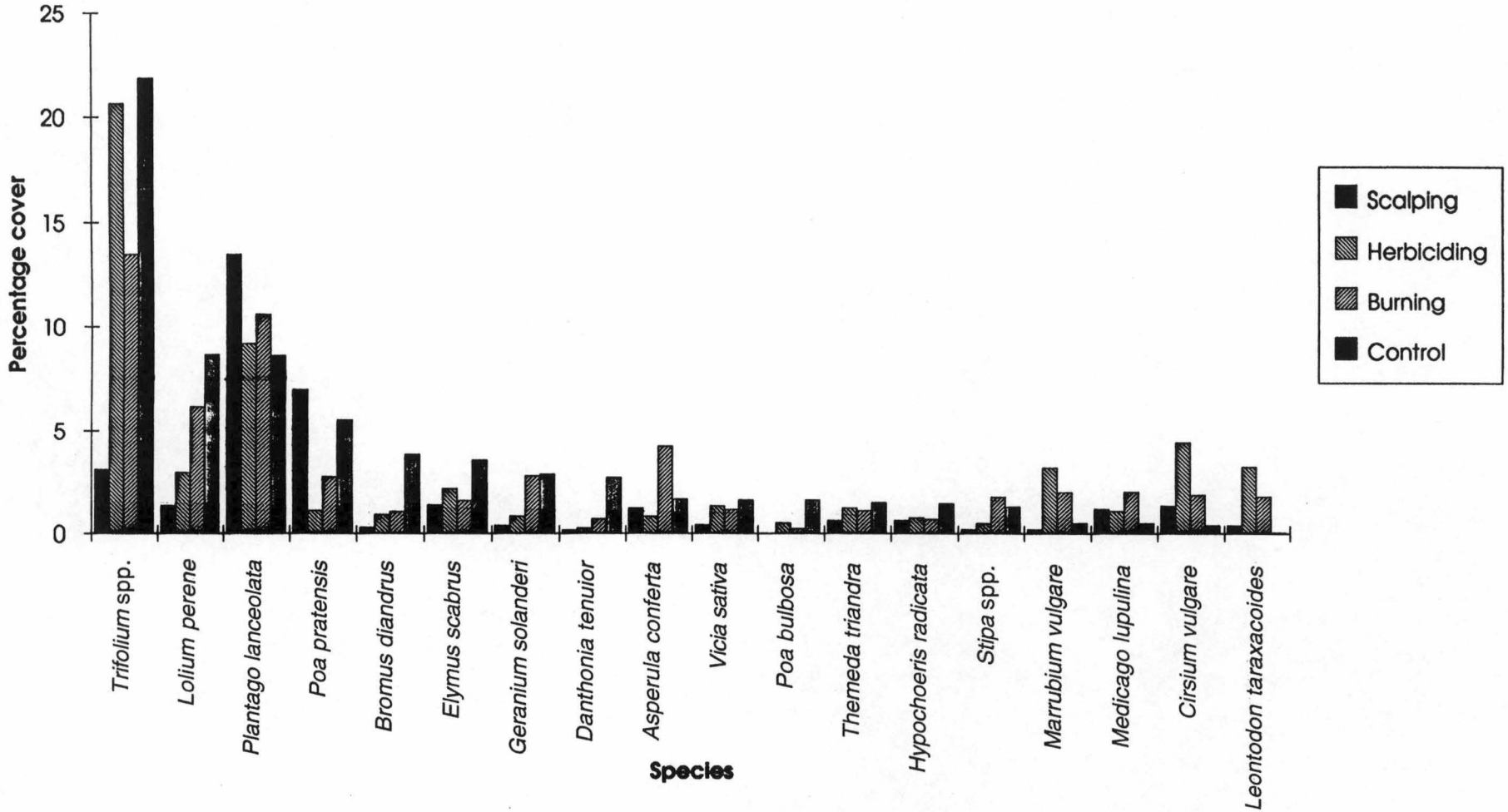

Fig. 6.2. Graph of mean percentage cover in 10 months after weed-control treatments (June 1992) of the 18 most abundant species in the weeded plots

Table 6.2. Least squares mean differences and standard deviations of the changes in cover of taxa, life-form groups and site attributes between, before and 10 months after weed-control treatments. The significance of differences between the pairs of treatments were calculated by t-tests using the least squares mean differences. Negative values of least squares means indicate less cover after 10 months. Where data are transformed for the pairwise comparisons, back-transformed least squares mean differences are shown

Therophytes	N	LSMean	SD		Scalp	Herb	Burn	Control
	30	-25.45	19.94	Scalp	.	ns	ns	0.0005
	30	-16.47	33.99	Herb		.	ns	0.0337
	30	-25.53	23.05	Burn			.	0.0004
	30	-3.35	29.33	Control				.
Exotic								
Bromus diandrus	N	LSMean	SD		Scalp	Herb	Burn	Control
	6	-8.50	14.18	Scalp	.	ns	ns	ns
	15	-13.90	24.91	Herb		.	ns	ns
	13	-10.65	19.95	Burn			.	ns
	15	-0.87	13.86	Control				.
Cirsium vulgare	N	LSMean	SD		Scalp	Herb	Burn	Control
	23	1.93	4.24	Scalp	.	ns	0.6889	0.0017
	29	4.59	7.75	Herb		.	0.0484	0.0001
	26	1.35	3.08	Burn			.	0.0041
	19	-2.08	8.13	Control				.
Cynosurus echinatus	N	LSMean	SD		Scalp	Herb	Burn	Control
	29	-17.69	14.16	Scalp	.	ns	ns	ns
	30	-18.57	14.96	Herb		.	ns	ns
	29	-17.57	12.62	Burn			.	ns
	29	-14.09	14.45	Control				.
Trifolium spp.	N	LSMean	SD		Scalp	Herb	Burn	Control
	28	-9.43	12.19	Scalp	.	0.0003	ns	0.0001
	29	4.93	20.30	Herb		.	0.0038	ns
	28	-6.09	16.45	Burn			.	0.0001
	29	11.19	17.37	Control				.
Silybum marianum	N	LSMean	SD		Scalp	Herb	Burn	Control
	12	0.63	0.61	Scalp	.	0.0003	ns	0.0001
	13	1.08	1.36	Herb		.	0.0038	ns
	10	0.25	1.36	Burn			.	0.0001
	5	0.90	0.89	Control				.
Vicia sativa	N	LSMean	SD		Scalp	Herb	Burn	Control
	19	0.13	1.23	Scalp	.	ns	ns	0.0216
	22	-2.50	11.98	Herb		.	ns	ns
	23	0.63	1.50	Burn			.	ns
	21	0.69	10.47	Control				.

Continued next page.

Table 6.2. Continued from above page.

Chamaephytes	N	LSMean	SD		Scalp	Herb	Burn	Control
	18	1.61	3.68	Scalp	.	ns	ns	ns
	27	3.33	9.96	Herb		.	ns	ns
	28	6.50	10.49	Burn			.	ns
	18	2.11	4.46	Control				.
Native chamaephytes								
Asperula conferta	N	LSMean	SD		Scalp	Herb	Burn	Control
	15	1.67	3.87	Scalp	.	ns	ns	ns
	11	-1.09	4.10	Herb		.	ns	ns
	18	5.88	11.77	Burn			.	ns
	15	2.80	5.07	Control				.
Exotic								
Marrubium vulgare	N	LSMean	SD		Scalp	Herb	Burn	Control
	11	0.36	1.42	Scalp	.	ns	ns	ns
	22	4.66	10.11	Herb		.	ns	ns
	21	3.86	5.75	Burn			.	ns
	9	-0.44	1.48	Control				.
Flat/vers rosette hemis	N	LSMean	SD		Scalp	Herb	Burn	Control
	30	11.68	9.79	Scalp	.	ns	ns	ns
	30	10.18	17.52	Herb		.	ns	ns
	30	12.20	12.81	Burn			.	ns
	29	6.81	7.06	Control				.
Native								
Rumex dumosus	N	LSMean	SD		Scalp	Herb	Burn	Control
	11	-0.91	1.04	Scalp	.	ns	ns	ns
	12	-1.25	1.31	Herb		.	0.0236	0.0226
	11	-0.50	0.71	Burn			.	ns
	12	-0.04	0.84	Control				.
Exotic								
Hypochoeris radicata	N	LSMean	SD		Scalp	Herb	Burn	Control
	27	-1.09	3.27	Scalp	.	ns	ns	0.0294
	25	0.00	8.78	Herb		.	ns	ns
	21	-1.76	4.92	Burn			.	0.0055
	23	-0.20	3.01	Control				.
Plantago lanceolata	N	LSMean	SD		Scalp	Herb	Burn	Control
	30	10.33	10.92	Scalp	.	0.0495	ns	ns
	29	5.81	10.98	Herb		.	ns	ns
	30	9.20	10.53	Burn			.	ns
	29	6.05	7.41	Control				.
Erect rosette hemis								
	N	LSMean	SD		Scalp	Herb	Burn	Control
	28	4.39	12.85	Scalp	.	ns	ns	ns
	18	1.61	6.95	Herb		.	ns	ns
	25	5.02	8.81	Burn			.	0.0171
	28	2.14	5.63	Control				.

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Table 6.2. Continued from above page.

Exotic							
Poa pratensis	N	LSMean	SD		Scalp	Herb	Burn	Control
	21	4.83	14.82	Scalp	.	ns	ns	ns
	12	2.67	6.20	Herb		.	ns	ns
	16	3.84	9.37	Burn			.	0.0379
	22	1.50	6.38	Control				.
Partial rosette hemis	N	LSMean	SD		Scalp	Herb	Burn	Control
	11	-0.41	4.33	Scalp	.	ns	ns	ns
	16	0.50	4.65	Herb		.	ns	ns
	15	2.33	5.64	Burn			.	ns
	7	-0.79	1.87	Control				.
Proto-hemis	N	LSMean	SD		Scalp	Herb	Burn	Control
	27	-1.98	3.83	Scalp	.	ns	0.0097	0.0200
	25	-1.56	5.21	Herb		.	ns	ns
	28	0.77	5.26	Burn			.	ns
	26	0.48	4.51	Control				.
Native proto-hemis								
Geranium solanderi	N	LSMean	SD		Scalp	Herb	Burn	Control
	27	-2.13	3.81	Scalp	.	ns	0.0058	0.0136
	25	-1.60	5.24	Herb		.	ns	ns
	28	0.62	5.25	Burn			.	ns
	26	-0.17	3.74	Control				.
Caespitose hemis	N	LSMean	SD		Scalp	Herb	Burn	Control
	30	-17.65	22.78	Scalp	.	0.0361	0.0008	0.0001
	30	-8.28	14.93	Herb		.	ns	0.0001
	30	-2.43	15.05	Burn		ns	.	0.0023
	30	11.35	17.56	Control				.
Native caespitose hemis								
Danthonia spp.	N	LSMean	SD		Scalp	Herb	Burn	Control
	7	-2.36	4.96	Scalp	.	ns	ns	0.0315
	6	-0.58	1.24	Herb		.	ns	ns
	13	1.88	4.27	Burn			.	ns
	17	2.79	6.53	Control				.
Elymus scaber	N	LSMean	SD		Scalp	Herb	Burn	Control
	14	-17.00	24.66	Scalp	.	ns	0.0476	0.0059
	14	-18.04	17.54	Herb		.	ns	0.0062
	15	-5.83	15.48	Burn			.	ns
	17	0.91	10.29	Control				.
Stipa spp.	N	LSMean	SD		Scalp	Herb	Burn	Control
	16	-0.28	1.39	Scalp	.	0.1001	0.0194	ns
	20	0.58	1.40	Herb		.	ns	ns
	21	1.88	3.74	Burn			.	ns
	18	2.19	4.88	Control				.
Themeda triandra	N	LSMean	SD		Scalp	Herb	Burn	Control
	16	-3.97	15.13	Scalp	.	ns	ns	0.0041
	15	-0.87	3.61	Herb		.	ns	ns
	15	-0.13	7.72	Burn			.	ns
	14	2.96	9.35	Control				.

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Table 6.2. Continued from above page.

Exotic caespitose hemis								
Lolium perenne	N	LSMean	SD		Scalp	Herb	Burn	Control
	24	-7.13	14.50	Scalp	.	0.0079	0.0256	0.0001
	26	-0.02	8.39	Herb		.	ns	0.0107
	28	-1.27	11.30	Burn			.	0.0023
	27	5.96	9.09	Control				.
Exotic grass	N	LSMean	SD		Scalp	Herb	Burn	Control
	30	-17.53	23.02	Scalp	.	ns	ns	0.0120
	30	-25.03	21.21	Herb		.	ns	0.0001
	30	-21.00	17.69	Burn			.	0.0011
	30	-6.58	19.05	Control				.
Exotic forb	N	LSMean	SD		Scalp	Herb	Burn	Control
	30	-0.93	14.86	Scalp	.	0.0001	0.0106	0.0010
	30	23.42	19.57	Herb		.	0.0019	0.0182
	30	10.00	19.90	Burn			.	ns
	30	13.33	18.82	Control				.
Native grass	N	LSMean	SD		Scalp	Herb	Burn	Control
	30	-11.68	23.02	Scalp	.	ns	0.0163	0.0001
	30	-7.53	15.22	Herb		.	ns	0.0029
	30	-2.65	11.20	Burn			.	ns
	30	3.73	10.85	Control				.
Native forb	N	LSMean	SD		Scalp	Herb	Burn	Control
	30	0.32	6.54	Scalp	.	ns	0.0015	ns
	30	-0.85	4.34	Herb		.	0.0023	ns
	30	5.92	11.05	Burn			.	0.0461
	30	2.25	6.71	Control				.
Total plant cover	N	LSMean	SD		Scalp	Herb	Burn	Control
	30	-29.83	28.05	Scalp	.	0.0013	0.0004	0.0001
	30	-10.00	26.22	Herb		.	ns	0.0003
	30	-7.73	18.24	Burn			.	0.0009
	30	12.73	27.26	Control				.
Bare ground	N	LSMean	SD		Scalp	Herb	Burn	Control
	30	58.33	14.58	Scalp	.	0.0001	0.0001	0.0001
	30	16.72	10.70	Herb		.	0.0001	ns
	30	34.67	12.61	Burn			.	0.0001
	30	10.80	11.04	Control				.
Total species richness	N	LSMean	SD		Scalp	Herb	Burn	Control
	30	-0.7		Scalp	.	ns	0.0014	ns
	30	0.7		Herb		.	ns	ns
	30	2.1		Burn			.	0.0191
	30	0.07		Control				.
Exotic species richness	N	LSMean	SD		Scalp	Herb	Burn	Control
	30	0.6		Scalp	.	ns	0.0125	ns
	30	1.83		Herb		.	ns	ns
	30	2.43		Burn			.	0.0086
	30	0.5		Control				.
Native species richness	N	LSMean	SD		Scalp	Herb	Burn	Control
	30	-1.35		Scalp	.	ns	0.0145	0.0359
	30	-1.17		Herb		.	0.0432	ns
	30	-0.35		Burn			.	ns
	30	-0.48		Control				.

The cover values of *Silybum marianum* and *Vicia sativa* were significantly less following scalping compared to the control, and *S. marianum* was also less following burning compared to the control. *Bromus diandrus* and *Cynosurus echinatus* had differences in mean cover but variances were larger and differences were not significant.

The cover of the species in the chamaephyte life-form group, *Asperula conferta* and *Marrubium vulgare,* were not significantly different following any of the treatments (Table 6.2).

The cover values of flat/versatile rosette hemicryptophytes as a group were not significantly different following any of the treatments compared to the control (Table 6.2). The variation in responses to herbiciding of *Rumex dumosus* was not significantly less than the control following this treatment. However, the herbicide treatment was the only treatment following which *Hypochoeris radicata* was not less than the control. *Plantago lanceolata* was the most abundant of the species in this group (Fig. 6.2). The cover values of *P. lanceolata* following scalping were significantly higher than following the herbicide treatment (Table 6.2). The regeneration of cover of *P. lanceolata* following scalping was mainly from resprouting of buds that were lower than the scalping blade level but also from deeply buried soil-stored seed. Other species, such as *Leontodon taraxacoides,* were moderately abundant in the quadrats and regenerated following some of the weed-control treatments (Fig. 6.2).

The cover values of the erect rosette hemicryptophyte group after burning were significantly higher than the levels of cover in the control quadrats (Table 6.2). *Poa pratensis* , the most common species of this group (Fig. 6.2), with an extensive and often dense underground rhizomatous root mat, was able to resprout quickly following scalping from buds deeper than the scalping depth. *P. pratensis* cover was not significantly different following any of the treatments compared to the control (Table 6.2).

The proto-hemicryptophyte life-form group and *Geranium solanderi,* which was the only abundant species in the life-form group, were significant less following the scalping treatments compared to the control.

The caespitose hemicryptophyte group had significantly lower cover following the three weed-control treatments compared to the control. Cover was lowest following scalping and next lowest following herbiciding and then burning (Table 6.2).

The cover values of the common native species, *Themeda triandra*, *Danthonia* spp. and *Stipa* spp. were significantly lower only following scalping compared to the control. *Elymus scaber* was less abundant following scalping and herbidicing. *Lolium perenne* was significantly lower following all the weed-control treatments (Table 6.2).

In some cases, the larger tussocks such as those of *Themeda triandra* still possessed live buds below the level of the scalping. However, the smaller tussocks, including *Danthonia* spp., were completely removed.

For most of the native species, except for *E. scaber*, the herbiciding did not appear to have a lethal effect. Burning killed only a few tussocks of both native and exotic species and tussocks regrew quickly. The cover of *Lolium perenne* was significantly lower than the control following all of the treatments (Table 6.2). The rate of regrowth appeared to be slower than for the native tussocks.

The sum of cover of exotic graminoids was significantly lower following all treatments compared to the control. Herbiciding resulted in lower cover than the other treatments (Table 6.2).

The sum of cover of exotic forbs, which include annual, biennial and perennial species of the therophyte and hemicryptophyte groups, was significantly less with scalping compared to the control. The highest cover was following the herbiciding treatment. The cover of exotic forbs following herbiciding was significantly higher than following scalping or burning (Table 6.2). Exotic forbs which were abundant following herbiciding included *Cirsium vulgare*, *Leontodon taraxacoides*, *Trifolium* spp., *Plantago lanceolata* and *Marrubium vulgare* (Fig. 6.2). The increase in exotic forb cover of 14% between August 1991 and June 1992 in the control quadrats was, to a large extent, due to the increase in the cover of *Trifolium* spp.

The cover of native graminoids was lower following scalping and herbiciding treatment compared to the control (Table 6.2). The cover was lower following burning, but not

significantly. The cover of native forbs, which were all perennial species, was significantly higher following burning than the other weed-control treatments (Table 6.2).

Total and exotic species richness increased significantly following burning compared to the control. Exotic and total species richness was next highest following herbiciding, scalping had no effect on exotic species richness (Table 6.2). Native species richness was significantly lower following scalping compared to the control.

6.3.4 Effects of weed-control treatments on the survival and flowering of transplants

Six out of 10 planted species had survival rates better than 50% (Table 6.3). These rates is a high considering that 1/4 were planted without any weeding treatment.

The deaths of almost all of the *Themeda triandra* tillers (Table 6.3), were most likely caused by the trauma involved in planting and soil and moisture conditions at the time of transplantation. In later glasshouse experiments approximately 70% of tillers when transplanted into potting media in nursery conditions were able to establish. Results of 80 - 90% survival of *Themeda triandra* tussocks have been achieved with the use of a propagation hot bed (M. Fountain, pers. comm.).

The overall significance of the effects of weeding treatments were high for numbers of sown plants surviving and flowering after 9 months (Table 6.4). All weed-control treatments resulted in higher levels of survival and flowering of the plantings compared to the control (Table 6.5). The numbers of plantings that survived following scalping was significantly higher than following herbiciding, but not significantly higher than in burned plots.

The number of plantings flowering was significantly higher for all weed-control treatments compared to the control. There were no significant differences in the numbers of plants flowering between the weed-control treatments (Table 6.5).

In this field experiment the planting of tillers into soil that was not able to be packed tightly around the roots would have caused moisture stress after planting. Due to the

low survival of tillers of *Themeda triandra* and seedlings of *Eucalyptus pauciflora*, no statistical analysis on those species were carried out.

Table 6.3. Numbers and percentages of transplants surviving and flowering 9 months after planting

	N	Survival		Flowering	
		N	%	N	%
Craspedia sp.	40	31	77.50	0	0.00
Acaena echinata	240	144	60.00	20	8.33
Vittadinia cuneata	80	48	60.00	14	17.50
Vittadinia muelleri	80	44	55.00	6	7.50
Leucochrysum albicans	320	171	53.44	65	20.31
Stipa stuposa	80	42	52.50	4	5.00
Plantago varia	40	14	35.00	1	2.50
Rumex dumosus	400	80	20.00	0	0.00
Eucalyptus pauciflora	40	6	15.00	0	0.00
Themeda triandra	1280	13	1.02	0	0.00
Total	2560	593	23.16	110	4.30

The total numbers of plants surviving in each quadrat were strongly correlated with plant cover 9 months after planting ($P < 0.001$) (Fig. 6.3). At 20% plant cover approximately 80% of plantings survived, the percentage decreasing to approximately 20% at 100% plant cover. The numbers of plants that flowered in each quadrat had a less strong but significant correlation with plant cover ($P < 0.01$) (Fig. 6.4).

Table 6.4. Table of significance of GLM model and differences between blocks and weeding treatments for numbers of sown plants surviving and flowering 9 months after planting

	Signif. of GLM	Block Effects	Weeding Treatment
No. plants surviving	0.0001	0.0123	0.0001
No. plants flowering	0.0123	ns	0.0001

Table 6.5. Table of significance of differences in numbers of planted individuals surviving and flowering per quadrat in the different weeding treatments as determined using least squares means

No. of	LS Mean		Scalp	Herb	Burn	Control
plants	9.90	Scalp	.	0.0331	ns	0.0001
surviving	7.70	Herb		.	ns	0.0004
	8.10	Burn			.	0.0001
	3.95	Control				.
No. of	LS Mean		Scalp	Herb	Burn	Control
plants	1.85	Scalp	.	ns	ns	0.0002
flowering	2.00	Herb		.	ns	0.0001
	1.65	Burn			.	0.0007
	0.00	Control				.

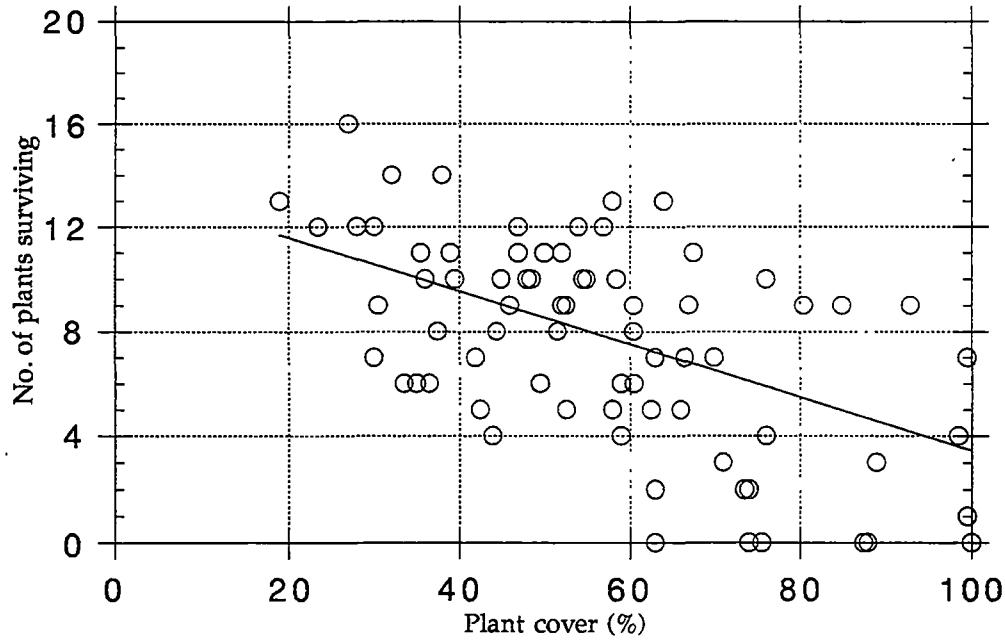

Fig. 6.3. Graph of numbers of plants surviving 9 months after planting against total plant cover. $r = 0.5409$, $P < 0.001$, $df = 78$

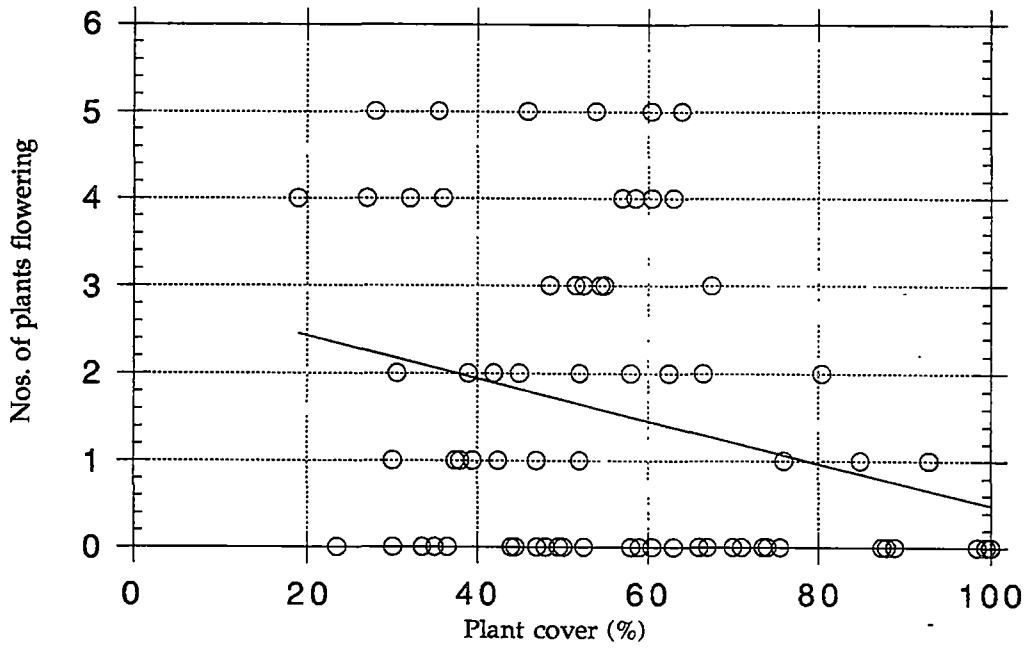

Fig. 6.4. Graph of numbers of plants flowering 9 months after planting against total plant cover. $r = 0.3042$, $P < 0.01$, $df = 78$

6.4 Discussion

6.4.1 Physical effects of weed-control treatments

Scalping

Scalping resulted in much lower cover values of most species of therophytes which rely on the soil seed bank for recruitment in the following season. This appears to indicate the general susceptibility to this treatment of annual species, particularly the annual grasses that rely on the soil-stored seed for recruitment in the following season. However, the notable exceptions were *Trifolium* spp. and *Cirsium vulgare* which established cover from abundant germinants.

Significant amounts of seed can be buried deeper than 3 – 5 cm and the soil seed store was usually a subset of the surface species (e.g. Gilfedder and Kirkpatrick 1993). Seeds may have been buried deeper than the scalping blade, for example by falling down cracks — facilitated by the deeply cracking nature of the clay soils. The seed may also have been carried down by invertebrates or buried by mechanical disturbances.

The cover of therophytes decreased because the disturbance was timed at a critical time of the year. McIntyre *et al.* (1995), found that therophytes were more abundant with soil disturbance. However, the types of soil disturbances were not directly comparable to scalping in this case.

The lack of decrease in cover values of flat/versatile rosette hemicryptophytes may have been largely due to the rapid recolonisation and resprouting by *Plantago lanceolata* and to a lesser extent other flat rosette weedy species, such as *Hypochoeris radicata.* Germination of *P. lanceolata* was probably much less important than resprouting in the establishment of cover, as mature resprouting individuals were able to recolonise at a quicker rate than seedlings.

For erect rosette hemicryptophytes the cover values that were greater following scalping than in the control and recolonisation were due largely to the rapid regrowth of *Poa pratensis*, which was able to regrow from a large number of buds that were below

scalping-blade depth. Large masses of *P. pratensis* rhizomes were uncovered by this technique. The other species of this group were of low importance.

The scalping treatments removed most of the seed bank, and resulted in the decrease in native species richness. The decrease in native species richness was partially counteracted by the recolonisation of a suite of exotic species, resulting in a slightly lower total species richness.

The effect of the removal of the nutrients in upper layers, which are considered to be important in favouring exotic species invasion and persistence (Clements 1983, Lambert and Turner 1987, Hobbs and Atkins 1988, Cale and Hobbs 1991), could not be isolated from the other effects of scalping. However, rapid regrowth of *Plantago lanceolata* in the scalped quadrats suggests that nutrient levels were not a limiting factor. The soils that develop on basalt are relatively fertile, for Tasmanian soils, and may have higher nutrient levels in the lower layers due to rubbish dumping and soil mixing caused by mechanical disturbance.

The rough surface that followed scalping contained abundant safe sites for seedling establishment as indicated by the prolific germination of *Cirsium vulgare*. However, in other soil types, scalping may produce a smooth soil surface or deeply cracking surface which would be less favourable. Other less destructive methods of reducing nutrient concentrations which do not promote flushes of annual species should be investigated. Possible techniques include the addition of carbon, which would allow soil bacteria to metabolise N and P.

Scalping creates an erosion risk depending on site conditions and would only be physically possible where soil type and rockiness permit. However, it is generally considered to be an effective preparation treatment for establishment of woody plant species, and has been recommended by Adair (1985), following herbicide application to destroy underground propagules.

Herbiciding

The faster recolonisation following the herbiciding treatment compared to the scalping treatment was predominantly due to rapid recolonisation by both annual and perennial

exotic forbs which may have been promoted by the presence of litter. Although the mean cover values of litter did not differ by more than 4.5% overall between treatments, particularly high cover values of *Cirsium vulgare* and *Trifolium* spp. seemed to be associated with high litter levels in some quadrats following herbiciding. This is consistent with the importance of mulch for the retention of soil moisture which resulted in more successful germination of *Cirsium vulgare* (Bullock *et al.* 1994).

This possibly important effect of the litter layer could also promote the survival of germinants of the perennial flat/versatile hemicryptophytes. However, this effect would be counteracted by the mortality of mature individuals caused by the herbicide.

High mortality of *Plantago lanceolata* was observed. This species has its slowest rates of recolonisation following herbiciding. The rapid recolonisation of other perennial exotic forbs *Leontodon taraxacoides* and *Marrubium vulgare* appeared to be due largely to recruitment from seed. However, some larger individuals survived to resprout. The residual herbicide would not be expected to remain active in the soil in levels high enough to have much effect on germination in the following season.

The factors that may be associated with sub-lethal effects of the herbicide are the level of activity at the time of the herbicide application, the presence of a large root mass compared to the shoot mass, the morphology of the leaves and possible resistance to the herbicides.

The observed non-lethal effect of herbicides on some of the tussock grasses including *Danthonia* spp. and *Stipa* spp., may be due to the leaf architecture, with the tightly rolled leaves presenting a low surface area and also possibly due to the stomata being on the inside of the rolled leaves. Another native species that has flat or loosely inrolled leaves, *Elymus scaber*, decreased following herbiciding. Sub-lethal effects of *Lolium perenne* were observed. However, this species was actively growing at the time and had green, flat leaves which would intercept the herbicide.

The observed non-lethal effect of herbicides on *Themeda triandra* was probably due to the lack of active growth it the time of application. As well, McDougall (1989*a*) found levels of resistance to the herbicides atrazine and fluazifop.

The lowest cover values of *Poa pratensis* following the weed-control treatment indicate the importance of the destruction of root material and the bud reserve. However, regeneration of *Poa pratensis* that occurred was probably a result of a large root mass and low shoot/root ratios in some quadrats. With *P. pratensis* higher concentrations of herbicide may be necessary.

Burning

The general opinion that burning favours native species over exotic species (Christensen and Burrows 1986) is only partly supported in this case. However, the cover of native species was low relative to the exotic species, as regeneration of some important exotic weedy species was rapid following the burn.

The cover of the exotic therophyte group was depressed following this treatment due to the disruption of seed set and recruitment for the following season and possibly the destruction of seed on the soil surface and in the litter by heating.

The cover abundance for caespitose hemicryptophytes was significantly lower. While there were few deaths of native tussocks, the time period involved was not large enough for pre-burning levels of cover to be reached.

The rapid regeneration of flat/versatile hemicryptophytes following burning is consistent with the observation by Groves (1989) that this group is hard to eradicate and is favoured by frequent burning. The rapid recolonisation in this case was due to the survival and quick resprouting of mature individuals of *Plantago lanceolata*, *Marrubium vulgare*, *Hypochoeris radicata* and *Leontodon taraxacoides*. Resprouting is likely to confer a competitive advantage compared to germination by allowing quicker assimilation, and pre-emption, of the flush of resources following the burn.

New germinants after the burn would not have had time to reach reproductive maturity before the drier months, and seed for the following years recruitment would be less. Therefore, following burning in spring, annual species would be disadvantaged relative to perennial species.

Early recolonisation in a situation of low competition for resources is likely to confer competitive advantage to the species that resprout compared to those that recruit by germination. This effect is pronounced in this case when the soils are rapidly drying. Burning also provides reduced competition for resources and a short-term flush of nutrients as ash.

Burning may be appropriate in some situations, to reduce particular species and to produce fast regeneration of other species. It may be used in combination with other treatments, for instance to stimulate the germination of weedy species so that they can subsequently be killed. The desirability of the stimulation of a soil seed bank depends on the relative numbers and importance of exotic and native species.

Burning in this experiment using an external heat source was aimed to produce consistent effects. However, wildfire intensity will depend on fuel weight and moisture, temperature and wind speed (Noble *et al.* 1980), and in some cases the fire will not carry.

6.4.2 Changes in the control quadrats

In the control quadrats, the 4% increase in plant cover and 8% increase in bare ground may have been real seasonal or annual differences, may have resulted from the different sampling scales used before and after the treatments, or may have resulted from differences in scoring due to differences in recognition of vegetation by the observer over time.

Determining cover values to the nearest 1% would be expected to increase the accuracy of assessment of vegetation cover and detection of treatment differences without greatly increasing the time taken. In this experiment, increased accuracy of vegetation cover assessment would have been highly desirable to pick up smaller but significant responses of species to disturbance.

6.4.3 Importance of species attributes and value of the life-form based analysis

Analysis of the responses of species aggregated to life-form groups was a useful tool in the understanding of community interactions and disturbance responses in this experiment. The responses of the species aggregated to life-form groups generally made ecological sense. McIntyre *et al.* (1995) found that the life-form classifications generally showed clear patterns of responses.

The responses of the life-form groups determined in a limited area compared to a broad-scale study will be less useful, since the results will be influenced by the responses of the most common species which are likely to be few in number.

In some cases, classification on the basis of the life-form groups used here grouped together species that were quite different in their responses. For example, the erect rosette hemicryptophyte group contained the rhizomatous exotic grass, *Poa pratensis*, which seems to thrive on disturbance and the tap-rooted, native forb, *Plantago varia* which is found in undisturbed areas. Also, the physiologies of the species are likely to be different.

Another example of a problem with the life-form classification is the use of the highest perennating buds. This means that *Asperula conferta*, is classed as a chamaephyte when what is critical to the regeneration of this species following disturbance is the presence of rhizomes and the ability to resprout prolifically from below-ground buds. A more useful classification of life-form for species in the context of Australian grass communities subject to disturbance could be the location of the lowest buds.

6.4.4 Implications for elimination of introduced species

The experiment indicates the relative effectiveness of weed-control treatments on different species which can be used in choosing appropriate options for particular situations. Importantly the experiment indicated that the different weed-control techniques favour different species of weeds. Panetta and Hopkins (1991) recommend the targeting of species that are likely to have greatest detrimental effect on weeds. In this study *Plantago lanceolata* which was a common at the site was not reduced by any

of the treatments, is an example of an intractable species which would need targeted weeding.

While the exotic species which have the greatest cover may be easily identified, the role of particular species or factors in causing the invasion or persistence of exotic species may not be apparent. As it is unlikely that one technique on its own would be effective in weed-control, combinations of control methods are recommended (Groves 1989).

6.4.5 Survival and flowering of transplants

The failure of *Themeda triandra* to establish meant that the native species that were introduced were all the interstitial subdominant species and unlikely to dominate the exotic vegetation.

Reduction of competition for water, nutrient and light resources from weeds is generally regarded as a critical factor affecting the success of establishing of plantings and seed. In this experiment, after an initial period of establishment, the mortality was low.

It would be expected that weed-control treatments in grasslands that reduced the live root mass of competing species would have the greatest positive effect on planting and seedling establishment. In this experiment the pre-existing root mass was most reduced by scalping and less so by herbiciding and not at all by burning. Herbiciding is likely to be a much more effective weed-control treatment at higher concentrations that are more effective at destroying extensive root systems.

Weed competition is less likely to affect seedlings when transplanted due to the prior development of a root system and the pre-emption of the soil space. Factors other than the reduction in competition that would affect the establishment of plantings are the moisture and nutrient conditions resulting from the different treatments. The effects include the litter produced with herbiciding, the soil fertilisation effect of burning, and the loss of soil nutrients occurring with scalping.

6.4.6 Applicability of using transplants in revegetation and restoration

The applicability of using plantings in revegetation projects is limited by the relatively high costs compared to direct seeding methods. The costs of revegetation per unit area are high but the results are more reliable than direct seeding methods. Transplanting of tubestock could be applicable for smaller areas where reliability, or a more controlled or uniform effect, is required. Transplanting could be used with other techniques.

The relative costs of planting compared to other establishment methods (Dawson 1991), preclude application to broad areas. However, planting could be used for introduction of particular species, or to increase species richness in a newly established or older sward. Transplants would be less critically affected by competition than direct seeded species.

Chapter 7. Determination of consistency of responses within life-form groups and determination of functional groups of taxa

7.1. Introduction

This chapter examines the levels of consistency of the responses of species within the Raunkiaer life-form groups to agricultural management, grazing, burning and weed-control techniques. The usefulness of using life-form group in the description of the general vegetation responses and the prediction of the likely response of a species to management regimes will be assessed.

7.2. Methods

7.2.1. Determination of matrix of species responses

Species responses to agricultural management (Chapter 2), grazing level (Chapter 4), burning (Chapter 5) and weed-control techniques (Chapter 6), were used in the analysis.

From the agricultural management chapter, the differences in species abundance in relation to levels of phosphorus in unsown, aerially sown and cultivated and sown pastures were used. This information was combined with the differences in species abundance between unsown and aerially sown, between unsown and sown pastures and between aerially sown and sown pastures.

From the comparison of grazing levels across the fencelines at TLNR, the differences that were used were those between the low and moderate grazing levels, the moderate and high grazing levels and the low and high grazing levels.

The examination of differences following burning involved a large number of comparisons between treatments. The differences in the cover of species with burning in June, September and November were combined, in that a difference for one of these months was referred to as a spring difference. The differences which were used in the analysis were single spring compared to both the no burn treatment and the single autumn burn treatment, and the consecutive year spring burns compared to both the no burn treatment and the consecutive year autumn burn treatments.

From the weed-control study, the differences in abundance of species in relation to the weed-control techniques which were used were the comparisons of scalping, herbiciding and burning to the control.

The differences in abundance of all species with the various management or disturbance variables were coded 1 = significantly less abundant, 2 = no significant difference and 3 = significantly more abundant (Table 7.1).

7.2.2. Determination of index of dissimilarity of responses of species

The responses of species in the following studies and combinations of studies were used:

- agricultural management;
- grazing level;
- burning;
- weed-control techniques;
- agricultural management and grazing level;
- agricultural management and burning;
- agricultural management and weed-control;
- agricultural management, grazing level and burning;
- grazing level, burning and weed-control;
- agricultural management, grazing level, burning and weed-control techniques.

Taxa were excluded from a comparison if there were insufficient data to allow a statistical test in any of the studies which were used for comparison.

For each of the studies and combinations of studies, matrices of the Gower metric index of dissimilarities were calculated for all the pairs of species using DECODA. The consistency of responses of species within a life-form group was calculated in the following way: firstly, the mean of the indices of similarity for all the pairs of species that were within a life-form group was calculated. Secondly, the mean of the indices of similarity between the species of the life-form group in question, and all the species which were not in the life-form group in question, was calculated. Thirdly, t-tests assuming unequal variances were used to determine whether the dissimilarities between pairs of species, where both species were in a life-form group, were significantly less than the dissimilarities between species of that life-form group and species of other life-form groups. Finally, if the mean index of dissimilarity was significantly less between species within a life-form group compared to the species of other life-form groups, then

the species of the life-form group were considered to have had similar responses and a degree of consistency of responses to disturbance.

7.2.3. Classification of species into groups with similar responses to disturbances

The polythetic, divisive program TWINSPAN (Hill 1979) was used to help sort the species into groups using the responses to the disturbance in the agricultural management, grazing level and burning studies. The species were treated as samples and the responses of the species to the different management or disturbances were treated as levels of sample variables. The responses were coded as above. Two groups were separated on the second level of division of TWINSPAN and 4 on the third level.

Table 7.1. Summary table of responses of species to disturbances involved in agricultural management, burning, grazing level and weed-control techniques. 1 = more abundant, 2 = no significant difference, 3 = less abundant and * indicates that the species was not found in sufficient quantities. P indicates difference with higher level of phosphorus, codes for pastures are u = unsown, a = aerially sown, s = sown. For comparison of grazing levels l = light, m = moderate and high = heavy. For burning 1 x and 2x indicate single and double burns respectively s = winter/spring, a= autumn, n = no burn. For weed-control techniques scalp = scalping, herb = herbiciding and burn = burning

	Agricultural management						Grazing			Burning						Weed-control techniques		
	P u	P a	P s	u - a	u - s	a - s	l - m	l - h	m - h	1 x s - a	1 x s - n	1 x a - n	2 x s - a	2 x s - n	2 x a - n	scalp	herb	burn
THEROPHYTES																		
Native																		
Crassula sieberana	2	3	2	2	2	3	*	*	*	*	*	*	*	*	*	*	*	*
Exotic																		
Aira caryophyllea	2	2	3	2	3	2	2	2	2	2	2	2	2	2	2	*	*	*
Aphanes arvensis	2	2	3	2	2	2	*	*	*	*	*	*	*	*	*	*	*	*
Arctotheca calendula	2	2	2	2	2	2	*	*	*	*	*	*	*	*	*	*	*	*
Briza minor	3	3	2	2	3	3	2	2	3	2	2	2	2	2	2	*	*	*
Bromus spp.	1	1	1	2	2	3	2	2	2	2	3	3	2	3	3	2	2	2
Capsella bursa-pastoris	2	2	1	2	3	2	*	*	*	*	*	*	*	*	*	*	*	*
Carduus spp.	1	2	1	3	3	2	*	*	*	*	*	*	*	*	*	*	*	*
Centaurium erythraea	2	2	2	2	2	2	2	2	3	2	3	2	1	3	3	*	*	*
Cerastium spp.	2	2	2	1	2	2	*	*	*	*	*	*	*	*	*	*	*	*
Cirsium vulgare	1	2	1	2	2	2	2	3	2	2	2	2	1	1	2	1	1	1
Cynosurus echinatus	2	2	2	1	2	3	2	3	2	2	2	2	2	3	2	2	2	2
Erodium cicutarium	2	2	1	2	2	2	*	*	*	*	*	*	*	*	*	*	*	*
Erodium moschatum	2	2	1	2	2	2	*	*	*	*	*	*	*	*	*	*	*	*
Hordeum marinum	2	2	2	2	2	2	*	*	*	*	*	*	*	*	*	*	*	*
Hordeum murinum	2	2	1	2	2	2	*	*	*	*	*	*	*	*	*	*	*	*

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	Pu	Pa	Ps	u-a	u-s	a-s	l-m	l-h	m-h	1x s-a	1x s-n	1x a-n	2x s-a	2x s-n	2x a-n	scalp	herb	burn
Moenchia erecta	2	3	3	2	2	2	*	*	*	*	*	*	*	*	*	*	*	*
Montia fontana	2	2	2	2	1	1	*	*	*	*	*	*	*	*	*	*	*	*
Myosotis discolor	1	2	1	1	2	3	*	*	*	*	*	*	*	*	*	*	*	*
Petrorhagia velutina	*	*	*	*	*	*	2	2	2	*	*	*	*	*	*	*	*	*
Poa annua	2	2	2	2	2	2	*	*	*	*	*	*	*	*	*	*	*	*
Silybum marinum	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	2	2	2
Trifolium spp.	1	2	2	2	1	2	2	2	2	2	2	2	2	2	2	3	2	3
Trifolium subterraneum	1	1	2	1	1	1	2	1	1	2	2	2	2	2	2	*	*	*
Vicia sativa	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	3	2	2
Vulpia spp.	1	2	2	2	1	2	*	*	*	2	2	2	2	2	2	*	*	*
CHAMAEPHYTES																		
Native																		
Acaena nova-zelandiae	2	2	3	2	2	1	*	*	*	*	*	*	*	*	*	*	*	*
Asperula conferta	*	*	*	*	*	*	2	3	3	2	2	2	2	2	2	2	2	2
Astroloma humifusum	*	*	*	*	*	*	2	2	2	*	*	*	*	*	*	*	*	*
Pimelea humilis	*	*	*	*	*	*	2	2	3	*	*	*	*	*	*	*	*	*
Exotic																		
Marrubium vulgare	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	2	2	2
GEOPHYTES																		
Native																		
Drosera peltata	3	2	3	3	2	1	*	*	*	*	*	*	*	*	*	*	*	*
FLAT/VERS ROSETTE HEMIS																		
Native																		
Ehrharta stipoides	2	2	2	3	3	2	*	*	*	*	*	*	*	*	*	*	*	*

Table continued next page

Table 7.1 Continued from above page

	P u	P a	P s	u - a	u - s	a - s	l - m	l - h	m - h	1 x s - a	1 x s - n	1 x a - n	2 x s - a	2 x s - n	2 x a - n	scalp	herb	burn
Gnaphalium spp.	2	3	2	3	3	3	*	*	*	*	*	*	*	*	*	*	*	*
Oxalis perennans	2	3	3	2	3	3	*	*	*	2	2	2	3	3	2	*	*	*
Ptilotus spathulatus	*	*	*	*	*	*	2	2	2	2	3	2	2	3	2	*	*	*
Rumex dumosus	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	3	2	3
Solenogyne dominii	3	2	3	1	2	3	2	2	2	*	*	*	*	*	*	*	*	*
Solenogyne gunnii	2	3	2	3	3	3	*	*	*	*	*	*	*	*	*	*	*	*
Exotic																		
Hypochoeris radicata	2	2	3	2	2	2	2	3	2	2	2	2	2	2	2	3	2	3
Leontodon taraxacoides	2	2	3	2	2	2	*	*	*	*	*	*	*	*	*	*	*	*
Plantago coronopus	2	2	2	2	2	2	*	*	*	*	*	*	*	*	*	*	*	*
Plantago lanceolata	2	2	2	1	2	2	2	2	1	2	2	2	2	2	2	2	2	2
Taraxacum officinale	2	2	1	2	2	2	*	*	*	*	*	*	*	*	*	*	*	*
Trifolium repens	1	2	1	1	1	3	1	2	2	2	2	2	2	1	2	*	*	*
ERECT ROSETTE HEMIS																		
Native																		
Acaena echinata	2	3	2	1	3	3	2	2	2	2	2	2	2	2	2	*	*	*
Carex spp.	2	3	2	1	3	3	2	2	3	2	2	2	2	2	2	*	*	*
Chrysocephalum apiculatum	*	*	*	*	*	*	2	2	2	2	2	2	2	1	2	*	*	*
Juncus spp	2	2	3	2	2	2	*	*	*	*	*	*	*	*	*	*	*	*
Plantago varia	2	3	2	3	3	3	2	2	2	2	3	3	3	3	2	*	*	*
Exotic																		
Agrostis capillaris	2	2	3	2	1	1	*	*	*	*	*	*	*	*	*	*	*	*
Poa pratensis	2	2	2	2	2	2	*	*	*	2	2	2	2	2	2	3	3	3
Tragopogon porrifolius	*	*	*	*	*	*	*	*	*	2	2	2	2	2	2	*	*	*

Table continued next page

Table 7.1 Continued from above page

	P u	P a	P s	u - a	u - s	a - s	l - m	l - h	m - h	1 x s - a	1 x s - n	1 x a - n	2 x s - a	2 x s - n	2 x a - n	scalp	herb	burn
PARTIAL ROSETTE HEMIS																		
Native																		
Leptorynchos squamatus	3	3	2	2	3	3	1	2	2	2	2	2	1	2	2	*	*	*
Lomandra nana	*	*	*	*	*	*	2	2	2	2	2	2	2	2	2	*	*	*
Exotic																		
Acetosella vulgaris	2	2	2	2	2	2	*	*	*	*	*	*	*	*	*	*	*	*
PROTO-HEMIS																		
Native																		
Convolvulus erubescens	3	3	2	2	3	3	2	2	2	2	2	2	2	2	2	*	*	*
Dichondra repens	3	3	2	2	3	3	2	2	2	*	*	*	*	*	*	*	*	*
Geranium spp.	3	3	2	2	3	3	2	2	1	1	1	1	2	2	2	3	2	2
Vittadinia cuneata	*	*	*	*	*	*	2	2	2	2	2	2	2	2	2	*	*	*
Vittadinia muelleri	*	*	*	*	*	*	2	2	3	2	2	2	2	2	2	*	*	*
CAESPITOSE HEMIS																		
Native																		
Danthonia spp.	3	3	3	1	3	3	1	2	2	2	2	2	2	3	2	3	2	2
Elymus scaber	2	2	2	2	3	2	*	*	*	2	2	2	2	2	2	3	3	2
Lomandra longifolia	2	3	2	3	3	3	*	*	*	*	*	*	*	*	*	*	*	*
Poa labillardierei	1	2	2	2	3	3	*	*	*	*	*	*	*	*	*	*	*	*
Poa rodwayi	3	2	2	2	3	3	1	2	2	*	*	*	*	*	*	*	*	*
Schoenus spp.	3	2	3	3	3	3	1	2	3	2	2	2	2	2	2	*	*	*
Stipa spp.	3	3	2	1	3	3	2	2	2	2	2	2	2	3	3	3	2	2
Themeda triandra	3	3	2	3	3	3	3	3	3	1	2	2	2	2	2	3	2	2

Table continued next page

Table 7.1 Continued from above page

	Pu	Pa	Ps	u-a	u-s	a-s	l-m	l-h	m-h	1xs-a	1xs-n	1xa-n	2xs-a	2xs-n	2xa-n	scalp	herb	burn
Exotic																		
Anthoxanthum odoratum	2	2	3	2	1	1	*	*	*	*	*	*	*	*	*	*	*	*
Dactylis glomerata	2	2	2	2	2	2	*	*	*	*	*	*	*	*	*	*	*	*
Holcus lanata	2	2	3	2	1	2	*	*	*	*	*	*	*	*	*	*	*	*
Lolium perene	1	1	1	1	1	1	2	2	2	2	2	2	2	3	2	3	3	3
Phalaris aquatica	2	2	3	2	2	2	*	*	*							*	*	*
Poa bulbosa	*	*	*	*	*	*	2	1	1	2	2	2	2	2	2	*	*	*
UNASSIGNED																		
Galium spp.	2	3	2	1	3	3	*	*	*	*	*	*	*	*	*	*	*	*

7.3. Results

7.3.1. Similarity of responses within life-form groups

Dissimilarity indices were significantly less for pairs of species of the same life-form group than with species in other life-form groups for 14 of 47 comparisons (Table 7.2). The similarity of responses of all life-form groups to the different disturbances was variable. Similarities of responses to disturbances in two separate studies did not necessarily result in similarities in the combination of the studies.

Agricultural management

The similarities in the responses of species cover to the phosphorus levels and sowing regimes were significant with therophytes ($P < 0.0001$), proto-hemicryptophytes ($P < 0.0001$) and caespitose hemicryptophytes ($P < 0.05$), but not with the other life-form groups (Table 7.2).

There was, however, variation within the relationships of species of life-form groups to the aspects of agricultural management. For example, the total cover of therophytes was higher with higher phosphorus in all types of pastures and with comparisons of the different sowing regimes (Chapter 2). However, the responses of therophytes species were variable. In unsown pastures, seven out of 23 therophyte species were more abundant with higher levels of phosphorus, one species was less abundant and 15 were not different (Table 7.2). The largest variation in the relationship of therophyte species cover with the level of an aspect of management was for the level of phosphorus in sown pastures. Eight species were more abundant, three were less abundant and 12 were not different (Table 7.1).

In the total of 132 comparisons of the 22 therophyte species, in only 27 were the species more abundant, in 91 there was no difference, and, in 14, the species decreased (Table 7.1). Therefore, the proportion of species which had the same response to the life-form group response was 20.5%, while 10% of species had the opposite response.

Table 7.2. Numbers of comparisons, means and standard deviations of dissimilarities between species of a life-form group and species of that life-form group compared to all species of other form groups, and in the case of hemicryptophytes, compared also to species of other hemicryptophyte subclasses. ***P < 0.001, **P < 0.01, *P < 0.05, ns = not significant

	same			others			Prob of diff	
	n	mean	SD	n	mean	SD	P	
Pasture								
Therophytes	506	0.263	0.019	874	0.332	0.026	0.0000	***
Flat/vers rosette hemis	110	0.312	0.023	550	0.310	0.025	ns	
Erect rosette hemis	30	0.322	0.032	330	0.312	0.028	ns	
Proto-hemis	6	0.000	0.000	174	0.349	0.029	0.0000	***
Caespitose hemis	156	0.380	0.040	624	0.344	0.031	0.0379	*
All hemis	1191	0.322	0.032	909	0.332	0.027	ns	
Burning								
Therophytes	56	0.269	0.004	112	0.285	0.010	ns	
Flat/vers rosette hemis	6	0.211	0.002	57	0.306	0.006	0.0024	**
Erect rosette hemis	6	0.175	0.009	57	0.248	0.008	ns	
Caespitose hemis	20	0.289	0.013	85	0.282	0.010	ns	
All hemis	182	0.264	0.009	112	0.285	0.010	ns	
Grazing								
Therophytes	72	0.204	0.024	234	0.220	0.034	ns	
Chamaephytes	6	0.222	0.007	96	0.155	0.017	ns	
Flat/vers rosette hemis	20	0.200	0.011	150	0.218	0.026	ns	
Erect rosette hemis	12	0.083	0.008	124	0.171	0.017	0.0062	**
Proto-hemis	20	0.133	0.011	150	0.172	0.021	ns	
Caespitose hemis	42	0.365	0.053	196	0.265	0.032	0.0110	*
All hemis	506	0.206	0.030	276	0.210	0.026	ns	
Weed-control								
Therophytes	30	0.311	0.061	72	0.292	0.063	ns	
Flat/vers rosette hemis	6	0.222	0.030	45	0.241	0.034	ns	
Caespitose hemis	20	0.167	0.018	65	0.249	0.042	0.0404	*
All hemis	90	0.200	0.017	80	0.283	0.057	0.0065	**
Pasture and burning								
Therophytes	72	0.252	0.006	153	0.275	0.011	ns	
Flat/vers rosette hemis	12	0.266	0.010	88	0.281	0.008	ns	
Erect rosette hemis	12	0.177	0.008	88	0.229	0.009	ns	
Caespitose hemis	30	0.275	0.010	120	0.263	0.010	ns	
All hemis	272	0.245	0.009	153	0.275	0.011	0.0046	**
Pasture and grazing								
Therophytes	56	0.312	0.014	136	0.315	0.027	ns	
Flat/vers rosette hemis	12	0.333	0.005	84	0.297	0.017	ns	
Erect rosette hemis	6	0.111	0.003	66	0.260	0.020	0.0000	***
Proto-hemis	6	0.074	0.006	66	0.231	0.026	0.0017	**
Caespitose hemis	30	0.348	0.055	114	0.311	0.033	ns	
All hemis	272	0.266	0.028	136	0.315	0.027	0.0058	**

Table continued next page

Table 7.2. Continued from above page

	same			others			Prob of diff	
	n	mean	SD	n	mean	SD	P	
Burning and grazing								
Flat/vers rosette hemis	12	0.167	0.001	100	0.170	0.010	ns	
Erect rosette hemis	12	0.167	0.010	100	0.173	0.013	ns	
Proto-hemis	12	0.167	0.019	100	0.182	0.019	ns	
Caespitose hemis	30	0.241	0.013	138	0.203	0.012	ns	
All hemis	380	0.177	0.012	180	0.196	0.015	ns	
Pasture, burning and grazing								
Therophytes	49	0.284	0.006	111	0.285	0.014	ns	
Flat/vers rosette hemis	6	0.306	0.017	54	0.264	0.010	ns	
Erect rosette hemis	6	0.300	0.002	54	0.243	0.010	0.0354	*
Caespitose hemis	20	0.258	0.019	80	0.317	0.012	ns	
All hemis	182	0.263	0.011	112	0.291	0.014	0.0415	*
Pasture, burning, grazing and weed-control								
Therophytes	12	0.315	0.003	28	0.335	0.016	ns	
Caespitose hemis	10	0.333	0.012	29	0.341	0.012	ns	
All hemis	41	0.308	0.009	29	0.333	0.015	ns	

Flat/versatile rosette hemicryptophytes consisted of similar numbers of native and exotic species. There was a considerable variation in the responses of species to the different aspects of management. The mean similarity was significantly less than for other groups. The native species were less abundant or were not significantly different in abundance with the higher levels of phosphorus or in aerially sown compared to unsown pastures or in sown pastures compared to aerially sown pastures, while the exotic species were more abundant or were not significantly different (Table 7.1).

The three species of proto-hemicryptophytes were all native and had an identical combination of responses. These species were less abundant with higher levels of phosphorus in unsown and aerially sown pastures, were no less abundant with aerial sowing than in unsown pastures, but were less abundant in sown pastures (Table 7.1).

The caespitose hemicryptophyte group, consisting of eight native and five exotic species, had considerable variation in abundance with the different levels of different aspects of management. The exotic species that appeared to be the most distinct from the others was *Lolium perenne* which was more abundant with phosphorus under all sowing regimes, and was more abundant in aerially sown compared to unsown pastures and in sown pastures compared to aerially sown pastures.

In contrast, *Themeda triandra* and *Schoenus* spp. were less abundant with higher levels of phosphorus and with aerial sowing, cultivation and sowing. *Poa labillardierei* was more abundant at higher levels of phosphorus in unsown pastures and *Danthonia* spp. and *Stipa* spp. were more abundant in aerially sown pastures than unsown pastures.

Grazing level

The life-form groups for which there was less dissimilarity between species within the group, compared to with species outside the group, were erect rosette hemicryptophytes ($P < 0.01$), caespitose hemicryptophytes ($P < 0.05$) and flat/versatile rosette hemicryptophytes ($P < 0.05$ compared to other hemicryptophytes) (Table 7.2).

The four native species of erect rosette hemicryptophyte, apart from *Carex* spp., were not different with the different grazing levels. However, caespitose hemicryptophytes varied considerably. *Themeda triandra* was less abundant with the heavier grazing

levels, while *Poa bulbosa* was significantly more abundant with heavy compared to both light and moderate grazing.

Burning

The only life-form group for which dissimilarity between species within the life-form groups was less than with species of other life-form groups was flat/versatile rosette hemicryptophytes ($P < 0.01$). Commonly flat/versatile rosette hemicryptophytes were not significant different following the different burn treatments. The two native species, however, were less abundant following some treatments.

Four out of six erect rosette hemicryptophytes had no differences in cover following any of the burns. *Plantago varia* was the major exception as it was less abundant following four out of six of the burn treatment comparisons.

Weed-control techniques

The caespitose hemicryptophyte life-form group was the only life-form group to have similar responses to the weed-control techniques ($P < 0.05$). The species in this life-form group were less abundant following scalping and the same or less abundant following the other treatments.

Combination of the studies

Agricultural management and grazing level

In the combination of the agricultural management and grazing level studies, there were consistent responses to disturbance within erect rosette hemicryptophytes, proto-hemicryptophytes and all hemicryptophytes (Table 7.3). The three species of erect rosette hemicryptophytes that were analysed in both studies were native. The species had identical responses except with the comparison of unsown and aerially sown pastures in which *Plantago varia* was less abundant while *Acaena echinata* and *Carex* spp. were more abundant (Table 7.1).

The proto-hemicryptophyte group also included all native species with almost identical responses. The only different was with the comparison of lightly and heavily grazed

areas in which *Geranium* spp. was more abundant and *Convolvulus erubescens* and *Dichondra repens* not significantly different (Table 7.1). In both cases the consistency of responses was based on only three native species. The small number of species suggests that cautions should be used in interpretation of the above results.

In the combination of agricultural management, level of grazing and burning studies, the erect rosette hemicryptophytes was the only life-form group with consistent responses (Table 7.1). As with the agricultural management and grazing level combination, the same three species were included and had near identical responses (Table 7.1).

7.3.2. Functional groups of taxa

Most of the TWINSPAN divisions were made on the basis of the responses of species to agricultural management. At the second level of division, two species were separated on the basis of lower abundance following a single spring burn compared to the control. There were no divisions made on the basis of the abundance of species in relation to grazing level. The species in each of the six groups had similar responses to agricultural management practices but, in many cases different responses to grazing and burning (Table 7.3).

Response group 1 consisted of three *Trifolium* spp. and *Lolium perenne,* which were more abundant under more intensive pasture management. All species were more abundant with higher levels of phosphorus in unsown pastures and all were more abundant in sown than unsown pastures. *Lolium perenne* and *T. repens* were more abundant with higher levels of phosphorus in sown pastures. The adventitious *Trifolium* spp. and *T. subterraneum* were not more abundant with higher phosphorus in sown pastures, as the cover values of the species were near the maximum amount at the low phosphorus levels (Table 7.3).

In most comparisons of cover between the different grazing levels, the species of this group were generally not significantly different. The exceptions were *T. subterraneum* which was more abundant in heavily grazed areas than the other areas, and *T. repens* which was more abundant with moderate compared to light grazing.

Table 7.3. Table of TWINSPAN analysis of the differences in abundance of species in the agricultural management, grazing level and burning studies. Life-form group: 1 = therophyte, 4 flat/versatile rosette hemicryptophyte, 5 = erect rosette hemicryptophyte, 7 = proto-hemicryptop and 8 = caespitose hemicryptophyte. Origin: 1 = exotic, 2 = native. Response: 1 = more abund 2 = no difference and 3 = less abundant

	life-form group	8411114114158855177488
	origin	11111111111222222122222
	species number	1111111111222
		123456789012345678901 2
grazing	light-heavy	2221332223222222222223
burning	1spring/autumn	2222222222222222221221
burning	1autumn/no burn	2222222222332222221222
burning	1spring/no burn	2222222232332222221222
grazing	mod/heavy	2221221232222223321233
grazing	light/mod	2122222222221222222113
burning	2autumn/no burn	2222222232322322222222
burning	2spring/autumn	2222122212232222222122
burning	2spring/no burn	3122132223333222222222
agric	phos level-sown	1122122323123222222232
agric	unsown-aerial	1121211222231111222233
agric	aerial-sown	1321232222333333333333
agric	unsown-sown	1111222322233333333333
agric	phos level-aerial	1221222222133333333323
agric	phos-unsown	1111122222123322333333
weed	scalping	3-3-122--3--33----3--3
weed	herbiciding	3-2-122--2--22----2--3
weed	burning	3-3-122--3--22----2--3
Response group		1111222333445555555566

no.	**Response group 1**	no.	**Response group 2**	no.	**Response group 3**
1	*Lolium perenne*	5	*Cirsium vulgare*	8	*Aira caryophyllea*
2	*Trifolium repens*	6	*Cynosurus echinatus*	9	*Centaurium erythraea*
3	*Trifolium* spp.	7	*Plantago lanceolata*	10	*Hypochoeris radicata*
4	*Trifolium subterraneum*				

no.	**Response group 4**	no.	**Response group 5**	no.	**Response group 6**
11	*Bromus* spp.	13	*Danthonia* spp.	21	*Schoenus* spp.
12	*Plantago varia*	14	*Stipa* spp.	22	*Themeda triandra*
		15	*Acaena echinata*		
		16	*Carex* spp.		
		17	*Briza minor*		
		18	*Convolvulus erubescens*		
		19	*Geranium* spp.		
		20	*Leptorynchos squamatus*		

There were also few differences with burning or the weed-control treatments. There were no significant differences with the comparisons of burn treatments, except with the two spring burns, following which *L. perenne* was less abundant compared to the control and *T. repens* was more abundant compared to the control. *L. perenne* was also less abundant following each of the weed treatments compared to the control (Table 7.3).

Response group 2 consisted of adventitious, exotic species which were commonly regarded as weeds in both unsown and sown pastures. None were more abundant in sown compared to unsown pastures. *Cynosurus echinatus* and *Plantago lanceolata* were not significantly different with different levels of phosphorus, but *Cirsium vulgare* was more abundant with higher phosphorus levels in unsown and sown pastures.

Apart from *P. lanceolata,* the species in this group were not more abundant with moderate or heavy grazing compared to the lighter grazed areas. *P. lanceolata* was more abundant with heavy grazing compared to moderate grazing.

C. vulgare was more abundant, while *C. echinatus* was less abundant, following the two consecutive burns in spring, and *C. vulgare* was more abundant following all the weed-control treatments (Table 7.3).

Response group 3 consisted of adventitious exotic species, mainly of unsown pastures. There were few differences with the aspects of intensive pasture management. However, *Aira caryophyllea* was less abundant in sown compared to unsown pastures, and less abundant with higher phosphorus levels in sown pastures.

Differences of species with grazing levels and burning treatments were few. Two of the species, *Hypochoeris radicata* and *Centaurium erythraea,* were less abundant in the heavily grazed area in comparisons with the other grazing levels. *Centaurium erythraea* had variable responses to burning (Table 7.3).

The division by TWINSPAN of the two species of response group 4 was based on lower abundance following the two consecutive autumn burns compared to the no burn treatment. However, the responses to agricultural management were opposite. *Bromus* spp. had higher phosphorus levels in pastures of the three sowing regimes, while

Plantago varia was less abundant under most aspects of intensive agricultural management. The cover of neither species was significantly different between the three grazing levels.

Response group 5 consisted of seven native species and *Briza minor*. Six species were less abundant with higher levels of phosphorus in unsown pastures, while all were less abundant with phosphorus in aerially sown pastures and less abundant in sown pastures than either unsown or aerially sown pastures. Only *Danthonia* spp. was present in sown pastures in sufficient quantities for a lower abundance to be recorded with higher phosphorus in these pastures.

Six species of this group were not significant different between lightly and moderately grazed areas, while *Danthonia* spp. and *Leptorynchos squamatus* were more abundant in the moderate grazed area compared to the lightly grazed area. *Geranium solanderi* was more abundant in the heavily grazed area than the moderately grazed area, while *Carex* spp. and *Briza minor* were less abundant.

Most species in this group were not significantly affected by the burning treatments. However, *Danthonia* spp. and *Stipa* spp. were less abundant following the two spring burns. In the weed-control technique study, *Danthonia* spp. and *Stipa* spp. were less abundant following scalping compared to the control (Table 7.3).

Response group 6 consisted of *Themeda triandra* and *Schoenus* spp. which, in contrast to the previous group, were less abundant with almost all of the aspects of intensive agricultural management. *Schoenus* spp. was more abundant with moderate grazing compared to light grazing but less abundant in the heavily grazed area, while *Themeda triandra* was less abundant with all levels of grazing level. The cover of *Themeda triandra* was increased following the single spring burn (Table 7.3).

7.4. Discussion

7.4.1. Predictability of responses to disturbance from life-form

The consistency of responses of species within life-form groups was a factor determining the usefulness of life-form groups as an aid to the description of responses

of vegetation to management. The moderate levels of similarity in the responses of species within life-form groups to the different factors in the studies indicate that if life-form was an important factor, it was only associated with some of the responses. The level of significance of similarity in responses within the life-form group tends to be higher if only native or only exotic species were considered.

In cases where differences in total cover of the species of life-form groups have been recorded, the trends often reflect the differences in cover of the most abundant species of the life-form group. However, even for a group such as therophytes, which had a significant trend with management, and a number of species with significant responses in the same direction as the life-form group trend, the proportion of species with an opposite trend was 10%, and overall almost 80% of species had a trend that differed from the life-form group.

In many cases there was no less dissimilarity between species within the life-form group than with species of other life-form group. It was also seen that the response of a species varied with the different combinations of climatic and edaphic conditions. The reliability of prediction of the response of any one species to a disturbance regime would therefore be low.

Studies of the numbers and proportions of species of life-form groups with different management regimes (McIntyre *et al.* 1995, Tremont 1994) have identified trends in the abundance of life-form groups, but have generally not assessed the consistency of the responses of individual species.

Noy-Meir *et al.* (1989) examined the responses to grazing level of grassland species and found that trends occurred. However, there was variation within life-form groups at a similar level to that shown in this study.

The variability in the responses to disturbance between species in life-form groups was consistent with the findings of other studies which identified other important factors associated with species responses to disturbances. These include stature (Noy-Meir *et al.* 1989), palatability (Friedel *et al.* 1988, Tremont and McIntyre 1994), phenology and dispersal characteristics (McIntyre *et al.* 1995). The classification of species into life-forms and the analysis of trends with the life-form provides a useful tool for

understanding the trends (McIntyre *et al.* 1995). However, it does not alone account for the vegetation response.

There were difficulties in assigning life-form classes to particular species. The morphologies of *Juncus* spp., *Lomandra longifolia* and *Lepidosperma laterale* and some grasses were intermediate between the caespitose and erect hemicryptophyte classes. Any classification scheme is essentially artificial, and there are always likely to be species which do not neatly fit into classes.

Others have found that chamaephytes and geophytes were comparatively rare in native grassy communities (McIntyre *et al.* 1994). The apparent rarity of geophytes and chamaephytes in the vegetation examined in the present study could be due either to reduction following long-term grazing or to pre-European absence of the life-form groups.

7.4.2. Functional groups of species

The groups of species which were classified according to their responses largely to agricultural management were analogous to functional groups of species (*sensu* Friedel *et al.* 1988, Leishman and Westoby 1992). The classification of species was dominated by responses to agricultural management.

The sorting of species into the groups mainly on the responses to agricultural management suggests that the directions and numbers of significant responses to agricultural management were greater than with the other disturbances examined in this thesis. The combined effects of grazing, fertilisation, mechanical disturbance and the introduction of exotic species appeared to be a more severe disturbance regime affecting native grassy woodland in southeastern Australia than any one of the disturbances alone. The comparison however involves responses of species to broad-scale management regimes with the responses to local and short-term applied disturbances of burning and weeding treatments.

The degree of replacement of native species with exotic species was related to the intensity of management for agricultural production. Fertilisation, sowing of seed of

exotic species and mechanical disturbance in varied habitats resulted in a wide variety of pasture types.

In the broad-scale survey of pastures no attempt was made to measure grazing pressure due to the difficulties in the estimation of the level of defoliation (Huntly 1991). However, it seems reasonable to assume that grazing was related, if not proportional, to the productivity of the site, and that productivity would have been largely related to nutrient level.

The similarity in responses to the levels of grazing in group 1 indicates that there was a consistency of tolerance to heavy grazing. Generally there was varied tolerance of heavy grazing with other groups. The distribution of species which were more abundant with heavy grazing compared to light or moderate grazing across the different response groups indicates that the response groups were not related primarily to the tolerance of grazing level in the pasture.

Flat architecture or low stature were the common factors in the species which were more abundant in the heavily grazed area compared to the more lightly grazed areas. The life-form and origin of the species did not appear to be important in the small subset of species which were common to the different studies and were compared.

Species which were more abundant following burning treatments compared to the control were distributed among the response groups.

Sequence of replacement of species

The replacement of native species with exotic species was gradual. The types of disturbance comprising management of pastures resulted in a wide variety of pasture types.

There was a sequence of disappearance of the native species, the life-form groups that were predominantly native and the native components of life-form groups, depending on the degree of tolerance of the exogenous disturbances. The intermediate disturbance hypothesis was supported as the total species richness under intermediate disturbance conditions was higher than either relatively low disturbance of stock grazing on its own

or the higher disturbance conditions resulting from a combination of grazing, burning, fertilisation and mechanical disturbance.

A similar progressive change in species composition was also recorded in the analysis of the effects of different grazing levels across the fencelines. The result of moderate grazing was an increase in a number of native species and a decline of the dominant *Themeda triandra*. The native species which were more abundant in the moderately grazed area were increasers (as in Noy-Meir *et al.* 1989). The lower stature of these species, with the bulk of their leaves and meristems closer to the ground predisposes them for tolerance of grazing.

Chapter 8. Conclusions and discussion

8.1. Impact of management on the species and life-form groups in Tasmanian grassy lowland vegetation

The results of the broad-scale survey of lowland pastures demonstrated that ploughing, fertilisation and sowing of exotic species altered the composition of the vegetation to varying degrees.

Ploughing, fertilisation and sowing of exotic species disadvantaged almost all native species and some exotic species. They promoted a wide variety of exotic species and some native species. The effects of the management regimes were influenced by differences in geology and precipitation.

The presence of sown species in improved pastures was in many cases temporary and, without continued maintenance by fertilisation and re-sowing, the pastures were re-invaded by a suite of native species. The lack of persistence of improved pasture species is a major concern for Tasmanian agriculturists (Thompson 1995, Martin 1995). It appeared that the likelihood of the sown pastures being re-invaded by native species was higher on drier and less fertile sites.

The impression from studies of the basalt plains of Victoria is that replacement of native species by exotic species is complete or near complete and that no conservation value exists in the pastures following pasture improvement (Lunt 1991, Stuwe and Parsons 1977). This thesis demonstrates that this is not the case in Tasmania where substantial areas of dry lowland sown and aerially sown pastures are semi-native. For much of the flora which is largely restricted to dry lowland grassy areas of Tasmania, conservation relies on maintenance of populations on privately owned land (Kirkpatrick *et al.* 1988).

As well as being important economically, semi-native pastures such as these may be important for nature conservation (McIntyre 1992). Very little is known regarding the management of semi-native pastures in temperate regions of Australia (Archer 1989). These pastures have both economic value and potential for the promotion of the native species component (Lodge and Whalley 1985).

In a study of pastures of the Northern Tablelands, New South Wales, McIntyre and Lavorel (1994*a*, 1994*b*), found that agricultural management practices and environmental factors had effects on vegetation of similar magnitude.

This study and the above however differ in important aspects including the ranges of the spectrum of improved through to native pastures which were examined. McIntyre and Lavorel (1994*a*, 1994*b*), focused mainly on the less disturbed and more native pastures. They did not include sown pastures. The variations in the intensity of management regimes were less. Therefore the differences in vegetation with management would be expected to be not as great compared to the variation in vegetation with environmental factors. The two studies also differed in the analysis methods used. In addition, McIntyre and Lavorel (1994*a*, 1994*b*), analysed a partially different set environmental parameters to this study.

In the present study, which covered a wide spectrum of pastures from ideal improved pastures of a few sown species to species rich native pastures, The management effects appeared to be of a greater magnitude than habitat differences. Larger numbers of taxa had significantly different abundances with the different management regimes with different environments. This study also demonstrated that some native species were able to persist following pasture improvement.

The partial replacement of native species by exotic species after pasture improvement, has been noted for the Goulburn region of New South Wales (Robinson *et al.* 1993). The varying degrees of alteration of vegetation were associated with soil type. Acidic and infertile soils had significant levels of *Danthonia* spp., *Ehrharta stipoides* and *Elymus scaber* (Robinson *et al.* 1993). Pasture composition was determined by both environment and management. Increased time since clearing and increased amount of added phosphorus were associated with higher cover of sown species and lower cover of native species (Robinson *et al.* 1993). Munnich *et al.* (1991) reported that the pasture types were associated with clearing history and types of machinery used.

However, on the fertile basalt plains in Victoria, alteration was near complete (Lunt 1991, Stuwe and Parsons 1977). The fertility of Victorian basalt soils appears to explain the completeness of pasture improvement as the higher nutrient levels in the soils

probably make them inherently more suitable for exotic species. Inherently infertile soils, or soils in which the nutrient levels decrease, are likely to be re-invaded by native species, while the pastures which either are more fertile, retain moderate to high nutrient levels or are intensively managed retain exotic species.

In the present study, the importance of fertility was indicated by the numbers of native species which appeared to respond negatively to increasing levels of phosphorus. In addition, the significant relationship of *Danthonia* spp. with both the level of phosphorus and the time since sowing indicates a relationship between the level of an important native species and phosphorus levels.

Agricultural management practices can be regarded as exogenous disturbances in that they are processes which disrupt community structure or change resource or substrate availability according to the definition of disturbance in Pickett and White (1985).

The four types of disturbance: managed grazing of stock, fertilisation, the sowing of seed of exotic species and cultivation have different severities and durations of impact in the pastures. Fertiliser addition, introduction of exotic species and mechanical disturbance are periodic, while managed grazing is often continuous.

Following the application of fertiliser there is a progressive decline in concentration. The level of phosphorus was associated with large differences in species composition and was a major factor determining grassland species composition in the present study. The role of fertility is a common theme in literature concerning the invasion of exotic species in Australian vegetation (Groves *et al.* 1973, Amor and Piggin 1977, Clements 1983, Lambert and Turner 1987, Hobbs and Atkins 1988, Hobbs 1989).

Exotic legumes were widespread in unsown areas, however, the abundance of legumes was greatly increased by the sowing of seed. As the presence of exotic legumes increased the availablility of nitrogen, it constituted a disturbance. The increased availability of nitrogen would further favour exotic species and aid their invasion of native grassy vegetation.

Cultivation is a periodic mechanical disturbance. Its effects could not be separated from the effects of the fertilisation and sowing of seed as it invariably occurs with them.

Interactions of nutrient enrichment and soil disturbance have been noted in the literature (Hobbs & Atkins 1988, Hobbs 1989, Collins 1987). Following cultivation and fertilisation the vegetation is more susceptible to the impacts of grazing (Robinson and Dowling 1976).

Moderate to heavy grazing is often a continuous disturbance in which the intensity of the managed grazing is raised above the levels that plants would normally experience from the native herbivores alone.

Following cultivation and decrease in phosphorus levels, under certain circumstances, native species re-invaded at a time following sowing. The result was often a community dominated by native species, but with a different composition to the original native species community. The re-invasion of improved pastures by native species can be seen as a successional proces.

The re-invasion of improved pastures was by grazing-tolerant native species such as *Danthonia* spp. Re-invasion by *Themeda triandra* would only be likely to occur if grazing ceased and the composition may then approach that of intact *Themeda triandra* grasslands.

Clementsian successional approaches are out of favour and are being replaced with transition-state models (Scanlan *et al.* 1991). Transition-state models may be a useful analysis tool for future description of floristic change in Tasmanian pastures under grazing management.

The three levels of grazing across the fencelines at TLNR resulted in three different floristic compositions and structures of vegetation. In the lightly grazed area, the high cover of the competitive dominant species *Themeda triandra* was associated with reduced richness of native interstitial species (*sensu* Grubb 1986). In the moderately grazed area, as the cover of the matrix species was reduced by grazing and intertussock spaces were larger, a greater richness of interstitial species was found. The high level of disturbance in the heavily grazed area resulted in only a limited number of native and exotic species of small stature and species richness was lower.

As the highest species richness was found at intermediate levels of disturbance, this study supports the intermediate disturbance hypothesis of Connell (1978). Fensham and Kirkpatrick (1989) also found that species richness is higher with grazing on fertile substrates, as was found at TLNR.

Collins (1987) considered the intermediate disturbance hypothesis to be inadequate to describe the complexities of the responses of vegetation to disturbances. In the comparison of grazing levels, however, where grazing is the main or only major disturbance, the intermediate disturbance hypothesis appears to be adequate.

The absence of native herbivores such as wallabies at TLNR is a result of the isolation of the remnant from larger areas of native vegetation. The light grazing by sheep is an unnatural grazing regime.

Compared to the differences in vegetation structure and floristics across the fencelines, burning in the different seasons had only minor impacts on the vegetation. Some of the significantly lower cover values following burn treatments compared to the no burn treatment would have been due to a lack time for plants to regenerate cover following the defoliation caused by the burn.

There were effects on therophytes, with an apparent promotion or disadvantaging of species with the timing of burns in relation to the life cycle of the species. However, there were relatively few significant differences compared to the grazing level differences.

Burning is non-selective in destruction of above-ground biomass, whereas the effect of grazing is selective toward particular species. Burning is a single defoliation event followed by regeneration whilst grazing involves many defoliation events. It is not surprising, therefore, that burning had few effects compared to grazing. The findings of this thesis agree with Belsky (1992), who also noted that fire had fewer effects on vegetation than grazing level or disturbance.

The effects of scalping and herbiciding on vegetation were greater than the effects of burning, due to destruction of above- and below-ground material. The strong effects were in line with expectations.

8.2. Correspondence of life-form groups with functional groups

This study is consistent with other studies (e.g. McIntyre *et al.* 1995, Noy-Meir *et al.* 1989, Belsky 1992), in that overall response trends were be found for life-form groups with a variety of management and disturbance regimes (Chapters 2, 4, 5 and 6). There appears to be consistency in the conclusions of the other studies that life-form group or a similar collective morphological classification was useful in understanding and describing responses of species to management and disturbance.

Generally the other studies did not directly test whether the species belonging to the life-form groups had statistically similar responses, that is the significance of life-form groups as a functional trait.

Another trait which was considered, but not directly examined in this study was the origin of the species. The testing of groups of species classified according to both life-form and origin would be likely to improve the description of vegetation responses. Although classification based on origin may not be transferable to other continents, in the Australian context this should be very useful. In addition, for the purposes of the description of responses of life-form groups to grazing level, a classification which considered the aspects of stature and palatability would be more appropriate than the normal classification.

The results in Chapter 7 indicated that for some types of disturbance and the combinations of different disturbance types the similarities in responses were greater within than between life-form groups. The similarities within life-form groups indicate that life-form group were to an extent equivalent with functional groups. However, the functional groups as identified in Chapter 2, contained a variety species belonging to different life-form groups.

In cases where there was correspondence between life-form groups and functional groups, the taxa of the life-form group tended to have the same origin, either exotic or native. For example, the responses of proto-hemicryptophytes and therophytes to pasture management were probably based on the largely native origin of the proto-hemicryptophytes and the largely exotic origin of the therophytes.

It is unrealistic to expect a collective trait such as life-form to account for responses of individual species to a disturbance regime or type of management regime. However, the results of this study support the use of growth form as in the life-form classification to describe patterns of vegetation response to a particular type of disturbance or disturbance regime.

In this study the functional groups of species for one type of disturbance regime did exihibit the similar responses to other types of disturbance. Similarly Belsky (1992) found that if species were grouped according to responses to one type of disturbance, then grouping of species regarding responses to other disturbances required division of the initial groups. Groups of species with responses to agricultural management had different responses to other disturbances and the groups (Chapter 7).

Belsky therefore concluded that functional groups that described responses to a range of disturbances could not be found in the grassland species that were studied. This indicates that species behaved individualistically in responses to a variety of disturbances. This consistent with the individualistic behaviour paradigm of Gleason (1926).

If predictions were to be made from responses of life-form groups or similar groupings, then they would be appropriate for the prediction of overall vegetation response to disturbances, rather than responses of individual species. The planning of regimes for management of vegetation for conservation purposes should, however, be based on responses of individual species.

Another trait which was considered, but not directly examined in this study was the origin of the species. The testing of groups of species classified according to both life-form and origin would be likely to improve the description of vegetation responses. Although classification based on origin may not be transferable to other continents, in the Australian context this should be very useful. In addition, for the purposes of the description of responses of life-form groups to grazing level, a classification which considered the aspects of stature and palatability would be more appropriate than the normal classification.

8.3. Appropriate management and restoration practices for grassy lowland vegetation areas managed for conservation

Discussion of the management of pastures on private land, which is primarily used for agricultural production, involves economic and practical considerations which are beyond the scope of this thesis.

Clearly, heavy grazing, the addition of fertiliser, the addition of the seed of exotic species and cultivation are all detrimental to the native component of pastures. This study supports the conclusions, drawn from other studies, that with grassy vegetation on fertile soils some form of biomass reduction may be necessary, as light grazing resulted in vegetation with higher species richness than in areas neither grazed nor burnt.

A light grazing regime reduces the competitive effects of the dominant *Themeda triandra,* and provides gaps for the regeneration of interstitial species and the seedlings of the structural dominants. Sufficient opening of gaps in the grass canopy can occur with light grazing pressure (Noy-Meir *et al.* 1989). However, at moderate levels of stocking, the growth of *Eucalyptus* spp. and other phanerophytes, and presence of a mid-storey of chamaephytes, may be inhibited by browsing.

Quantification of the level of grazing is important as the effects increase exponentially (Robinson and Dowling 1976). In this thesis, estimations of the degree of grazing pressure by the number of scats and the stated stocking rates were approximate, and description of the differences in grazing level between sites was relative. It would be useful to gain more accurate measures of grazing pressure. The rate of stocking should not be determined on exotic species alone but include native herbivores, especially in the run country (cf. Leigh and Holgate 1979).

The results of this thesis indicate the importance of the timing of grazing and rest periods. The effects of the timing of rest periods from grazing have rarely been studied. An example where manipulation of periods of resting and heavy grazing caused alternation in species composition is shown by Lodge and Whalley (1985). It is likely that the timing of rest periods, at consistent times over a number of years, would have important and long-term effects. The strategic manipulation of grazing and resting

periods where differences in phenology occur could alter vegetation composition to a desired state.

The most important time for spelling native pastures to allow production of seed would generally be September to January, however, the year-to-year variability of seasons would require adjustment of spelling times and prescription by calendar dates would not be reliable.

Grazing until early spring and then spelling the area could have a similar effect to burning in winter and early spring, which promoted the growth of *Themeda triandra*. Therefore, spelling from spring onwards would be likely to promote *T. triandra*.

Light stock grazing could be appropriate in conservation reserves. However, the conservation management agency would be responsible for ensuring that particular rare and threatened species are not adversely affected.

In the present study, burning in autumn resulted in lower abundance of native species compared to exotic species. It could be expected also that grazing which continued over summer, and ceased at the onset of winter, would be expected to favour exotic species.

The results of the present study suggest that burning in any particular season will be likely to promote the species which normally have a period of active growth in the season following the burn. The observation that native species were reduced by autumn burning and exotic species were not, suggests that, if exotic species are present in substantial amounts, then burning before late spring would be preferable to burning in autumn.

If the post-fire germination and growth of exotic species are not likely to be a problem, then timing of regular burning could be varied to reduce the possibility of disadvantaging any particular group of native species.

The results of the present study suggest that if native grassland contains the C_4 grass, *Themeda triandra* and C_3 species, then *Themeda triandra* will be favoured by early spring burning and disadvantaged by late spring and summer burning. A varied burning time could reduce the risk of disadvantaging any groups of species with similar

phenologies. For example, regular spring burning in North American prairies stimulated dominant warm season grasses and has, in many areas, reduced the diversity of cool season interstitial species (Howe 1994).

If exotic species are present, burning in autumn would be likely to promote their growth and germination. Burning at any time would be likely to stimulate the germination of exotic seed. The winter and early spring periods would be most suitable for the growth of the new germinants and exotic perennials.

This study found a depressive effect on the cover of exotic therophytes following the single and consecutive September burns, but not following autumn burns. This differs from the findings of Victorian studies (McDougall 1989*a*, Robertson 1985), where there were no clear differences between areas burnt in spring and in autumn. The identification of reasons for the differences in results would require comparative studies of the species and habitats.

Burning on its own had a significant negative effect on exotic species in the present study. Therefore, burning has potential both in biomass reduction and in weed-control. This contrasts with a recommendation of caution against the use of burning on its own as a management tool by Lunt (1990).

Even destructive weed-control techniques, such as scalping and the use of non-selective herbicides, could be selective. Different weed-control techniques favour and disadvantage different sets of species.

Burning was also shown to have selective effects. The more destructive and effective weed-control techniques could be used in conjunction with manipulation of the burning and grazing regimes in areas with variable species composition and patchy exotic species distribution.

Weed-control methods that are based on knowledge of the ecology and responses to disturbance of species in an area are likely to provide the best results (Lunt 1991). For example, with exotic annual species, scalping would be the most effective weeding treatment as it largely removes the transient soil seed bank. Herbiciding and burning treatments can be effective if they are carried out in critical stages in the life cycle, and

late in the growing season, before seed maturation and dispersal. Spraying of lower concentrations of herbicides in the winter months, known as 'winter cleaning' when practiced in crop situations, may be effective with annual species. The results of the present study suggest that this treatment may not be lethal to native tussock grasses. However, the mulch created by herbiciding promoted the establishment and growth of *Trifolium* spp. and *Cirsium vulgare.*

For exotic perennial species such as *Lolium perenne,* scalping would be the most effective weeding treatment, as burning and herbiciding were ineffective in this case. In contrast, for *Poa pratensis* and *Plantago lanceolata* herbiciding was the most effective weeding treatment. While scalping is effective, the cover of *Poa pratensis* may be increased relative to other species.

For native perennial grasses burning has the least detrimental effect. However, native grasses may not be harmed by some types of herbicides and low concentrations of other herbicides.

A combination of techniques could be used in a grassy community such as TLNR where densities of exotic species would vary. Burning in particular seasons, and variations in the types and application rates of the herbicides, could be used for weed-control in largely native or semi-native communities.

In conclusion, management should be based on likely responses of individual species. Management should aim to promote desirable species and disadvantage undesirable species. It therefore follows that the species composition will determine appropriate methods for management. Management of native vegetation should be both species- and site- based.

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Appendix 1. Full list of higher plant taxa found in the pasture survey and at Township Lagoon Nature Reserve

Conservation status codes follow Kirkpatrick et al. (1991). Nomenclature follows Buchanan (1995).

Conservation status:

E taxa that are likely to become extinct if present land use changes and patterns and other causal factors of decline continue;

e as above for Tasmania only;

v taxa that are likely to become extinct but over longer period that than e;

r2 taxa that occur in 20 or less 10 km x 10 km National Mapping grid squares in Tasmania;

en after the name indicates endemic;

i indicates introduced species.

Survey code:

Pasture survey	p
TLNR	t

Species and genera which were postively identified are listed.

DICOTYLEDONAE

AMARANTHACEAE			
	Ptilotus spathulatus	p	t
APIACEAE (UMBELLIFERAE)			
	Apium prostratum		t
	Daucus glochidiatus	p	t
	Eryngium vesiculosum	p	
	Hydrocotyle callicarpa	p	
	Hydrocotyle sibthorpioides	p	
	Hydrocotyle spp. = *H. callicarpa & H. sibthorpioides*	p	
	Lilaeopsis polyantha		t
	Trachymene humilis		t
ASTERACEAE (COMPOSITAE)			
i	*Achillea millefolium*	p	
i	*Arctotheca calendula*	p	
i	*Bellis perennis*	p	t
	Brachyscome aculeata		t
r2	*Brachyscome rigidula*		t
	Brachyscome spp.	p	
r2	*Calocephalus lacteus*		t
i	*Carduus pycnocephalus*	p	
i	*Carduus* spp. = *C. pycnocephalus & C. tenuiflorus*	p	
i	*Carduus tenuiflorus*	p	

	Chrysocephalum apiculatum	p	
	Chrysocephalum semipapposum	p	
	Chrysocephalum spp. = *C. apiculatum & C. semipapposum*	p	
i	*Cirsium arvense*	p	
i	*Cirsium vulgare*	p	t
	Cotula australis	p	
i	*Cotula coronopifolia*		t
E	*Craspedia* sp. (Tunbridge - undescribed)		t
	Gnaphalium spp. = *G. collinum*	p	
	Helichyrsum scorpioides	p	
i	*Hypochoeris glabra*		t
i	*Hypochoeris radicata*	p	t
i	*Hypochoeris* spp. = *H. radicata & H. glabra*	p	
e	*Isoetopsis graminifolia*		t
i	*Leontodon taraxacoides*	p	t
	Leptorhynchos squamatus	p	t
	Leucochrysum albicans var. *incanum*	p	t
	Microseris lanceolata		t
	Podolepis jaceoides		t
	Rutidosis multiflora	p	
i	*Scorznera laciniata*		t
	Senecio quadridentatus		t
	Senecio spp. = *S. quadridentatus & S. linearifolius*	p	
i	*Silybum marianum*	p	t
	Solenogyne dominii	p	t
	Solenogyne gunnii	p	t
i	*Sonchus asper*	p	t
i	*Sonchus oleraceus*	p	t
i	*Taraxacum officinale*	p	t
i	*Tragopogon porrifolius*		t
r2	*Vittadinia cuneata*		t
v	*Vittadinia gracilis*		t
r2	*Vittadinia muelleri*		t
BORAGINACEAE			
	Cynoglossum suaveolens		t
i	*Echium vulgare*		t
i	*Myosotis discolor*	p	t
BRASSICACEAE			
i	*Brassica rapa*	p	t
i	*Capsella bursa-pastoris*	p	t
i	*Cardaria draba*	p	t
i	*Erophila verna*		t
Eue	*Lepidium hyssopifolium*		t
i	*Rapistrum rugosum*		t
i	*Sisymbrium officinale*	p	
CAMPANULACEAE			

	Pratia pedunculata	p	
	Wahlenbergia spp.	p	
	Wahlenbergia stricta		t
	CARYOPHYLLACEAE		
i	*Cerastium vulgare*	p	
i	*Cerastium glomeratum*	p	t
i	*Cerastium* spp. = *C. vulgare & C. glomeratum*	p	
i	*Moenchia erecta*	p	t
i	*Petrorhagia nanteuilii*	p	t
i	*Petrorhagia velutina*	p	
i	*Polycarpon tetraphyllum*	p	
i	*Sagina apetala*	p	
	Scleranthus biflorus	p	t
v	*Scleranthus diander*	p	t
i	*Silene gallica*		t
i	*Spergula arvensis*	p	
i	*Spergularia media*		t
i	*Spergularia rubra*	p	
i	*Stellaria media*	p	
	CHENOPODIACEAE		
	Einadia nutans subsp. *nutans*		t
	CLUSIACEAE (GUTTIFERAE, HYPERICACEAE)		
	Hypericum gramineum	p	t
	CONVOLVULACEAE		
i	*Convolvulus arvensis*	p	
	Convolvulus erubescens	p	t
	Dichondra repens	p	t
r2	*Wilsonia rotundifolia*		t
	CRASSULACEAE		
	Crassula sieberana	p	t
	DILLENEACEAE		
	Hibbertia hirsuta	p	
	Hibbertia riparia		t
	Hibbertia serpyllifolia	p	t
	Hibbertia spp. = *H. serpyllifolia*	p	
	DROSERACEAE		
	Drosera peltata subsp. *auriculata*	p	
	Drosera peltata subsp. *peltata*	p	t
	EPACRIDACEAE		
	Acrotriche serrulata		t
	Astroloma humifusum	p	t

	Epacris impressa	p	
	Leucopogon collinus	p	
	Lissanthe strigosa	p	t
	EUPHORBIACEAE		
	Poranthera microphylla	p	
	FABACEAE (LEGUMINOSAE)		
	Bossiaea prostrata	p	t
	Bossiaea riparia		t
	Daviesia ulicifolia		t
i	*Lotus* spp. = *L. corniculatus*	p	
i	*Medicago lupulina*	p	t
i	*Medicago polymorpha*	p	t
i	*Medicago sativa*	p	
i	*Medicago* spp. = *M. lupulina & M. polymorpha & M. sativa*	p	
e	*Pultenaea prostrata*	p	t
	Pultenaea spp.	p	
i	*Trifolium dubium*	p	t
i	*Trifolium fragiferum*	p	
i	*Trifolium glomeratum*	p	t
i	*Trifolium hybridum*	p	
i	*Trifolium pratense*	p	
i	*Trifolium repens*	p	t
i	*Trifolium* spp. = *P. dubium, P. glomeratum & P. striatum*	p	
i	*Trifolium subterraneum*	p	t
i	*Ulex europaeus*	p	t
i	*Vicia sativa*	p	t
i	*Vicia* spp. = *Vicia sativa & V. hirsuta*	p	
	FUMARIACEAE		
i	*Fumaria* spp.		t
	GENTIANACEAE		
i	*Centaurium erythraea*	p	t
i	*Cicendia filiformis*	p	t
	Sebaea ovata	p	
	GERANIACEAE		
i	*Erodium botrys*	p	t
i	*Erodium cicutarium*	p	t
i	*Erodium moschatum*	p	
i	*Erodium* spp. = *E. botrys, E. cicutarium & E. moshcatum*	p	
	Geranium potentilloides	p	t
	Geranium solanderi	p	t
	Geranium spp. = *G. solanderi & G. potentilloides*	p	
	Pelargonium australe		t
	Pelargonium spp.	p	

GOODENIACEAE			
	Goodenia lanata	p	t
	Selliera radicans		t
uv	*Velleia paradoxa*		t
HALORAGACEAE			
	Gonocarpus tetragynus	p	t
	Gonocarpus teucrioides	p	
LAMIACEAE (LABIATAE)			
i	*Marrubium vulgare*	p	t
i	*Prunella vulgaris*	p	
LINACEAE			
	Linum marginale		t
MALVACEAE			
i	*Malva* spp.	p	
i	*Malva sylvestris*	p	
MIMOSACEAE			
	Acacia dealbata	p	t
	Acacia mearnsii	p	
	Acacia melanoxylon	p	
	Acacia spp. = *A. dealbata, A. mearnsii*	p	
MYRTACEAE			
	Eucalyptus amygdalina	p	
	Eucalyptus globulus	p	
	Eucalyptus ovata	p	
	Eucalyptus pauciflora	p	t
	Eucalyptus viminalis	p	
ONAGRACEAE			
	Epilobium billardierianum	p	
OXALIDACEAE			
	Oxalis perennans	p	t
i	*Oxalis pes-caprae*	p	
PITTOSPORACEAE			
	Bursaria spinosa	p	
PLANTAGINACEAE			
i	*Plantago coronopus*	p	t
i	*Plantago lanceolata*	p	t
i	*Plantago major*		t
i	*Plantago* spp. = *P. coronopus, P. lanceolata & P. major*	p	
	Plantago varia	p	t

POLYGONACEAE			
i	*Acetosella vulgaris*	p	t
	Polygonum spp.	p	
i	*Rumex crispus*	p	t
	Rumex dumosus	p	t
i	*Rumex obtusifolius*	p	
i	*Rumex* spp. = *R. crispus*	p	
PORTULACACEAE			
	Calandrinia menziesii	p	
i	*Montia fontana*	p	
PRIMULACEAE			
i	*Anagallis arvensis*	p	t
RANUNCULACEAE			
	Ranunculus lappaceus	p	t
i	*Ranunculus muricatus*	p	
en	*Ranunculus prasinus*		t
i	*Ranunculus repens*	p	
	Ranunculus spp. = *R. lappaceus, R. muricatus & R. repens*	p	
RESEDACEAE			
i	*Reseda luteola*		t
ROSACEAE			
	Acaena agnipila	p	t
	Acaena echinata	p	t
	Acaena novae-zelandiae	p	
	Acaena ovina	p	t
	Acaena spp. = *A. agnipila, A. echinata & A. ovina*	p	
i	*Aphanes arvensis*	p	
i	*Cotoneaster glaucophyllus*		t
i	*Crataegus monogyna*		t
i	*Rosa canina*	p	
i	*Rosa rubiginosa*	p	t
i	*Rosa* spp. = *R. canina & R. rubiginosa*	p	
i	*Rubus fruticosus*		t
RUBICAEAE			
	Asperula conferta	p	t
	Coprosma quadrifida	p	t
	Galium australe		t
i	*Galium aparine*		t
i	*Galium murale*	p	t
	Galium spp. = *G. murale & G. australe*	p	
SCROPHULARIACEAE			

i	*Parentucellia latifolia*	p	t
i	*Parentucellia viscosa*	p	
i	*Verbascum thapsus*	p	
	Veronica gracilis		t
	Veronica spp.	p	
	SOLANACEAE		
i	*Lycium ferocissimum*		t
	STACKHOUSIACEAE		
Ee en	*Stackhousia gunnii*		t
	THYMELAEACEAE		
	Pimelea humilis	p	t
	Pimelea spp.	p	
	TREMANDRACEAE		
	Tetratheca spp.	p	
	VIOLACEAE		
	Viola hederacea	p	t
	Viola spp. = *V. hederacea*	p	
	MONOCOTYLEDONAE		
	CENTROLEPIDACEAE		
	Aphelia pumilio	p	
	Centrolepis aristata	p	
	Centrolepis strigosa	p	
	CYPERACEAE		
	Carex breviculmis	p	t
	Carex inversa	p	
	Carex iynx	p	
	Carex spp. = *C. breviculmis, C. inversa & C. iynx*	p	
	Cyperus spp. = *C. tenellus*	p	
	Cyperus tenellus	p	
	Isolepis platycarpa	p	
	Isolepis spp. = *I. platycarpa*	p	
en	*Lepidosperma inops*		t
	Lepidosperma laterale	p	
	Lepidosperma longitudinale	p	
R r2 en	*Schoenus absconditus*	p	t
	Schoenus apogon	p	t
	Schoenus spp. = *S. apogon & S. absconditis*	p	
	IRIDACEAE		
	Diplarrena moraea	p	

i	*Romulea rosea*	p	t
	JUNCACEAE		
i	*Juncus bufonius*	p	
i	*Juncus capitatus*	p	
	Juncus pallidus	p	
	Juncus procerus	p	
i	*Juncus* spp.*1* = *J. bufonius & J. capitatus*	p	
	Juncus spp.2 = *J. procerus & J. pallidus*	p	
	Luzula meridionalis	p	t
	Luzula spp.	p	
	JUNCAGINACEAE		
	Triglochin centrocarpum	p	
	LILIACEAE		
	Arthropodium milleflorum	p	t
r2	*Arthropodium minus*	p	t
	Arthropodium spp. = *A. milleflorum & A. minus*	p	
	Bulbine bulbosa	p	
r2	*Dianella longifolia* var. *longifolia*		t
	Dianella revoluta		t
	Dianella tasmanica	p	
	Dichopogon strictus	p	
	Hypoxis hygrometrica	p	t
	Hypoxis spp. = *H. hygrometrica*	p	
	Wurmbea dioica subsp. *dioicia*	p	t
	Wurmbea uniflora	p	
	ORCHIDACEAE		
	Corybas spp.		t
	Diuris lanceolata		t
	Microtis spp.	p	
	Microtis unifolia		t
	Prasophyllum odoratum		t
	Pterostylis commutata		t
	Spiranthes australis		t
	Thelymitra pauciflora		t
	POACAEAE (GRAMINEAE)		
	Agrostis aemula		t
i	*Agrostis capillaris*	p	t
i	*Agrostis stolonifera*	p	
i	*Aira caryophyllea*	p	t
i	*Alopecurus* spp.	p	
i	*Anthoxanthum odoratum*	p	
i	*Arrhenatherum elatius*	p	t
i	*Avena fatua*		t
i	*Avena sativa*	p	

i	*Avena* spp. = *A. sativa & A. fatua*	p	
i	*Briza minor*	p	t
i	*Bromus catharticus*		t
i	*Bromus diandrus*	p	t
i	*Bromus hordeaceus*	p	t
i	*Bromus* spp. = *B. hordeaceus & B. diandrus*	p	
i	*Bromus sterilis*	p	
i	*Cynosurus cristatus*	p	
i	*Cynosurus echinatus*	p	t
i	*Dactylis glomerata*	p	t
	Danthonia caespitosa	p	t
	Danthonia carphoides var. *angustior*		t
	Danthonia pilosa		t
	Danthonia setacea	p	
	Danthonia setacea var. *setacea*		t
	Danthonia spp. = *D. caespitosa, D. setacea & D. tenuior*	p	
	Danthonia tenuior		t
	Deyeuxia quadriseta	p	t
	Dichelachne crinata	p	t
	Dichelachne rara	p	t
	Dichelachne spp. = *D. crinita & D. rara*	p	
	Distichlis distichophylla		t
	Ehrharta stipoides	p	t
i	*Elymus repens*	p	t
	Elymus scaber	p	t
i	*Festuca arundinacea*	p	
en	*Festuca plebeia*	p	
i	*Hainardia cylindrica*	p	
i	*Holcus lanatus*	p	t
i	*Hordeum marinum*	p	t
i	*Hordeum murinum*	p	t
i	*Lolium multiflorum*	p	
i	*Lolium perenne*	p	t
	Pentapogon quadrifidus	p	t
i	*Phalaris aquatica*	p	
i	*Phalaris minor*	p	
i	*Poa annua*	p	t
i	*Poa bulbosa*	p	t
	Poa hookeri	p	t
	Poa labillardieri	p	t
i	*Poa pratensis*	p	t
	Poa rodwayi	p	t
	Poa sieberiana	p	
	Poa spp.	p	
	Puccinellia stricta		t
	Stipa flavescens		t
r2	*Stipa nodosa*	p	t
	Stipa scabra	p	
	Stipa semibarbata		t

	Stipa spp. = *S. stuposa, S. nodosa & S. scabra*	p	
	Stipa stuposa	p	
	Themeda triandra	p	t
i	*Vulpia bromoides*	p	
i	*Vulpia myuros*	p	t
i	*Vulpia* spp. = *V. myuros & V. bromoides*	p	
	XANTHORRHOEACEAE		
	Lomandra longifolia	p	
	Lomandra nana	p	t

PTERIDOPHYTA

	ADIANTACEAE		
	Cheilanthes austrotenuifolia	p	t
	DENNSTAEDTIACEAE		
	Pteridium esculentum	p	